

**OFF-FIELD MOVEMENT AND DISSIPATION  
OF SOIL-INCORPORATED CARBOFURAN  
FROM THREE COMMERCIAL RICE FIELDS,  
AND POTENTIAL DISCHARGE  
IN AGRICULTURAL RUNOFF WATER**

**March, 1990**

**ENVIRONMENTAL HAZARDS ASSESSMENT  
PROGRAM**



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OFF-FIELD MOVEMENT AND DISSIPATION OF SOIL-INCORPORATED  
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AND POTENTIAL DISCHARGE IN AGRICULTURAL RUNOFF WATER

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ENVIRONMENTAL HAZARDS ASSESSMENT PROGRAM

## ABSTRACT

Residues of carbofuran (Furadan®; 2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) were detected in agricultural drain water collected in the Sacramento Valley, a major rice growing region of California. Runoff water from rice (*Oryza sativa* L.) and sugar beet (*Beta vulgaris* L.) fields were determined to be potential sources for these residues. In response to this problem, mass discharge of carbofuran from three commercial rice fields in Colusa and Glenn Counties, in California, was measured. Potential discharges of carbofuran from rice and sugar beet runoff water in a three-county area were then estimated and compared. In addition, dissipation of soil-incorporated carbofuran from rice paddy soil and water was examined for 70 to 80 days after fields were flooded.

Maximum concentrations of carbofuran in runoff water ranged from 21 to 33  $\mu\text{g L}^{-1}$  and occurred within 26 days after initial flooding of rice fields. A total of 1.72, 5.40 and 11.03% of carbofuran mass applied was discharged in runoff water from Fields 1, 2 and 3, respectively, during a 54 to 80 day period after flooding. The potential mass of carbofuran discharged into agricultural drains in Colusa, Glenn and Yolo Counties was estimated to be approximately 11 times greater from rice (461 kg) than from sugar beet (41 kg) fields during April through July, 1988.

Maximum average concentrations of carbofuran in paddy soil ranged from 0.50 to 0.80  $\text{mg kg}^{-1}$  and occurred within 11 to 20 days after flooding the fields. Maximum average concentrations of carbofuran in paddy water ranged from 24.5 to 38.2  $\mu\text{g L}^{-1}$  and occurred within 1 to 28 days after flooding the fields.

Dissipation of carbofuran mass from rice paddy soil and water was a log-linear function of time. An exception occurred in paddy soil of Field 3 where carbofuran mass did not decline significantly over a 70 day sampling period. Soil half-lives, estimated from these functions, were 58 and 43 days after flooding for Fields 1 and 2, respectively. Water half-lives for Fields 1, 2 and 3 were 22, 26 and 18 days, respectively. Most of the carbofuran mass applied to the fields remained in paddy soil and, on average, no more than 27% of the applied mass was found in paddy water on any single day during the study.

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Collection and analysis of agricultural drain water samples by personnel from the Department of Fish and Game was greatly appreciated.

Finally, our special thanks to the growers for their cooperation and patience.

## **DISCLAIMER**

The mention of commercial products, their source or use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such product.

## TABLE OF CONTENTS

	Page
Abstract.....	i
Acknowledgements.....	ii
Disclaimer.....	ii
Table of Contents.....	iii-iv
List of Figures.....	v
List of Tables.....	vi
 I. Introduction.....	 1
II. Materials and Methods.....	3
Study Sites.....	3
Agricultural Drains.....	7
Application Rates.....	7
Sample Collection.....	10
Field Runoff and Agricultural Drain Water.....	10
Dissipation from Rice Fields.....	12
Quality Control and Chemical Analysis.....	14
Calculations.....	15
III. Results and Discussion.....	20
Mass Discharged from Rice.....	20
Rice vs. Sugar Beet.....	27
Dissipation from Paddy Soil and Water.....	32
Mass Recovered from Paddy Soil and Water.....	36
IV. Conclusions.....	38
V. References.....	41
Appendix I. California Department of Fish and Game laboratory methods for analysis of carbofuran in agricultural drain water samples, 1988.	
Appendix II. Split sample results for carbofuran in rice paddy soil and water.	
Appendix III. Part A. Data for calculations of water volume released and carbofuran mass discharged from rice fields in Colusa and Glenn Counties, CA, 1988.	
Appendix III. Part B. Daily volume of water released, percent of total volume released, daily mass of carbofuran discharged and percent of total mass discharged for three rice fields in Colusa and Glenn Counties, CA, 1988.	
Appendix IV. Concentrations of carbofuran in runoff water from three sugar beet fields, Colusa County, CA, 1988.	

- Appendix V.     Part A. Calculations of carbofuran potential discharge values for rice fields in Colusa, Glenn and Yolo Counties, CA, 1988.
- Part B. Calculations of carbofuran potential discharge values for sugar beet fields in Colusa, Glenn and Yolo Counties, CA, 1988.
- Appendix VI.    Carbofuran concentration and mass in paddy soil and water from three rice fields in Colusa and Glenn Counties, CA, 1988.

## LIST OF FIGURES

	Page
Figure 1. Fields were located adjacent to the source of irrigation water, the Glenn-Colusa Canal, in Colusa and Glenn Counties, California. Water flowed through fields via weir boxes or pipes (  ) and runoff was sampled at outlets. Samples of soil and water were also collected around the perimeters of bottom paddies where carbofuran was applied (shaded areas)...	4
Figure 2. Agricultural drain water sampling locations along the Colusa Basin Drain (■) and its tributaries (▲) in the Sacramento Valley, California.....	8
Figure 3. Daily mass of carbofuran discharged, after initial flooding, in runoff water from three rice fields. Arrows indicate beginning (↓) and ending (↑) points of the water holding period for molinate applications.....	25
Figure 4. Daily average carbofuran concentrations and daily volume of runoff water released from three rice fields, after initial flooding. Arrows indicate beginning (↓) and ending (↑) points of the water holding period for molinate applications.	26
Figure 5. Total mass of carbofuran used per week in Colusa, Glenn and Yolo Counties vs. concentrations of carbofuran in water (detection limit $1.0 \mu\text{g L}^{-1}$ ) at the CBD1 agricultural drain site in Yolo County, California, 1988.....	30
Figure 6. Carbofuran water concentrations (detection limit $1.0 \mu\text{g L}^{-1}$ ) found at agricultural drain sampling sites in Colusa and Yolo Counties, California, 1988.....	31

# LIST OF TABLES

	Page
Table 1. Schedule of events for three rice fields monitored for carbofuran dissipation and runoff.....	6
Table 2. Carbofuran application rates, total and treated field areas, and total amounts of carbofuran applied to three fields in Colusa and Glenn Counties, California.....	9
Table 3. Sampling frequency and sampling periods for measurement of carbofuran in runoff water released from three rice fields...	11
Table 4. Sampling schedule for measurement of carbofuran dissipation from soil and water of bottom rice paddies in Fields 1, 2 and 3.....	13
Table 5. Calculated volume of runoff water and number of days of runoff from three rice fields in Colusa and Glenn Counties, California, 1988.....	21
Table 6. Calculated carbofuran mass discharged in runoff water and percent of applied carbofuran moved off-field in runoff water from three rice fields in Colusa and Glenn Counties, California, 1988.....	22
Table 7. Runoff loads for carbofuran discharged in runoff water from three rice fields for three time periods after initial flooding.....	23
Table 8. Concentrations and days of maximum carbofuran residues in runoff water from three rice fields, and days water was held on fields due to molinate application.....	28
Table 9. Maximum average (n = 3) concentrations of carbofuran found after flooding rice fields and final average (n = 3) concentrations found in soil and water of bottom paddies of three rice fields.....	33
Table 10. Regression analyses of carbofuran dissipation in paddy soil and water and calculated half-lives.....	34
Table 11. Carbofuran mass and percent of applied carbofuran recovered from soil and water in bottom paddies of rice fields. Total mass recovered from soil and water as percent of carbofuran mass applied.....	37

## INTRODUCTION

The California Department of Food and Agriculture (CDFA), in conjunction with other state agencies, conducts an ongoing program to control the discharge of rice pesticides into surface waters. During monitoring in 1987, residues of a broad spectrum systemic insecticide, carbofuran (Furadan®; 2,3-Dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate), were found in agricultural drains in the Sacramento Valley and in the Sacramento River. Carbofuran residues were found most consistently and at highest concentrations in May and early June in the Colusa Basin Drain (CBD), a large agricultural drain contributing a major portion of irrigation return flow to the Sacramento River. In a three-county area encompassing the CBD, applications of carbofuran, from the latter part of April through June 1987, were made exclusively to rice (*Oryza sativa* L.), a flooded crop, and sugar beet (*Beta vulgaris* L.) a row crop. Caro et al. (1973) reported high concentrations of carbofuran ( $> 1,000 \mu\text{g L}^{-1}$ ) in irrigation runoff water from a row crop, indicating that runoff water from sugar beet fields may have contributed a portion of the residues found in agricultural drain water. The major portion of carbofuran residues found in agricultural drain water probably originated from rice since approximately 12 times more carbofuran was applied to rice than sugar beet fields (9,414 vs. 757 kg a.i., respectively) (CDFA, 1987), and the volume of runoff water is greater for rice.

The behavior of carbofuran in the rice field environment needs to be understood in order to develop regulatory strategies to control off-field movement. Under neutral and basic environmental conditions the primary mechanism of carbofuran degradation in soil and water is hydrolysis (Getzin, 1973; Seiber et al., 1978). The rate of hydrolysis increases with increasing pH and temperature. Persistence of carbofuran in soil may be increased by: soil-incorporation methods of application; granular formulation; high soil organic matter content; and low soil pH, temperature and moisture (Caro et al., 1973; Getzin, 1973; Ahmad et al., 1979; Miles et al., 1981; Ou et al., 1982; Harris et al., 1988). Several factors with modest influence on the dissipation of carbofuran in water include evaporation, photolysis and oxidation (Seiber et al., 1978; Deuel et al.,

1979). Recently, carbofuran application methods in rice fields, in counties surrounding the CBD, have changed from broadcasting granules onto the soil surface (without soil incorporation) to incorporating granules into the soil of the top one or two paddies, or in some cases entire fields. Agricultural commissioners have requested this change in order to prevent poisoning of the water fowl which feed at the water's edge as the first paddies are initially flooded. Caro (1973) determined that incorporation of carbofuran in a row crop increased persistence and reduced the mass of carbofuran available to move off-field in runoff water. The effect of incorporation of carbofuran granules has not been studied in rice fields.

This study was undertaken since carbofuran studies published in the literature were conducted using various formulations and methods of application not used for rice, or under environmental conditions different from those found in the rice growing regions of California. The purpose of this study was two-fold: first, to quantify the mass of carbofuran discharged in runoff water from rice fields and use this information to compare hypothetical estimations of carbofuran discharged from rice and sugar beet fields in a three-county area; and second, to examine dissipation of incorporated carbofuran from rice paddy soil and water.

## MATERIALS AND METHODS

### Study Sites

Three commercial rice fields located in Colusa and Glenn Counties, California, were selected for determining the concentrations of carbofuran in runoff water and paddy soil and water. Fields 1, 2, and 3 had total areas of 24, 34, and 32 ha, and bottom paddy areas of 6.5, 2.8, and 5.3 ha, respectively (Fig. 1). Each field had only one inlet and outlet. Fields 1 and 2 both contained two soil types, Hillgate clay (Typic Pelloxerert) and Myers clay (Entic Chromoxerert); Field 3 contained Willows clay (Typic Pelloxerert) (Begg, 1968). Organic matter content in soil averaged 2.4% in Field 1, 2.2% in Field 2, and 2.8% in Field 3. Soil bulk density was  $1.4 \text{ g cm}^{-3}$  for Field 1 and  $1.3 \text{ g cm}^{-3}$  for Fields 2 and 3. Carbofuran had been applied to all of the fields in previous years. Average background soil concentrations of carbofuran were  $0.02 \text{ mg kg}^{-1}$  (near the detection limit of  $0.01 \text{ mg kg}^{-1}$ ) for all three fields.

Fields were cultivated to a depth of approximately 15 cm by chiseling, discing, and tri-planing. A 5% granular formulation of carbofuran was applied using a broadcast spreader mounted on a liquid fertilizer ground rig 4 to 10 d prior to flooding. Carbofuran is used to control the rice water weevil (*Lissorhoptrus oryzophilus* Kuschel) which migrates into the paddies from the weeds growing along levees and roads; therefore, carbofuran is generally applied only to the borders of rice paddies. Granules were applied to one, or in some places two, 6.27 m wide swaths around the borders of each paddy in Fields 1 and 2, and incorporated to a depth of about 5 cm with a rice roller preceded by a spring-tooth harrow attachment. In Field 3 carbofuran was applied to two 7.39 m swaths (14.78 m total width) around the borders of the paddies and incorporated with a harrow to a depth of 1 to 3 cm. Carbofuran was applied to Field 1 on 16 April, Field 2 on 12 April and Field 3 on 14 April 1988. After application Fields 1 and 2 were rolled; Field 3 was rolled between the disc and tri-plane operations.

Just prior to flooding a Stevens A 35 graphic recorder was installed in a 61 cm diameter stilling well at the outlet of each field to take continuous

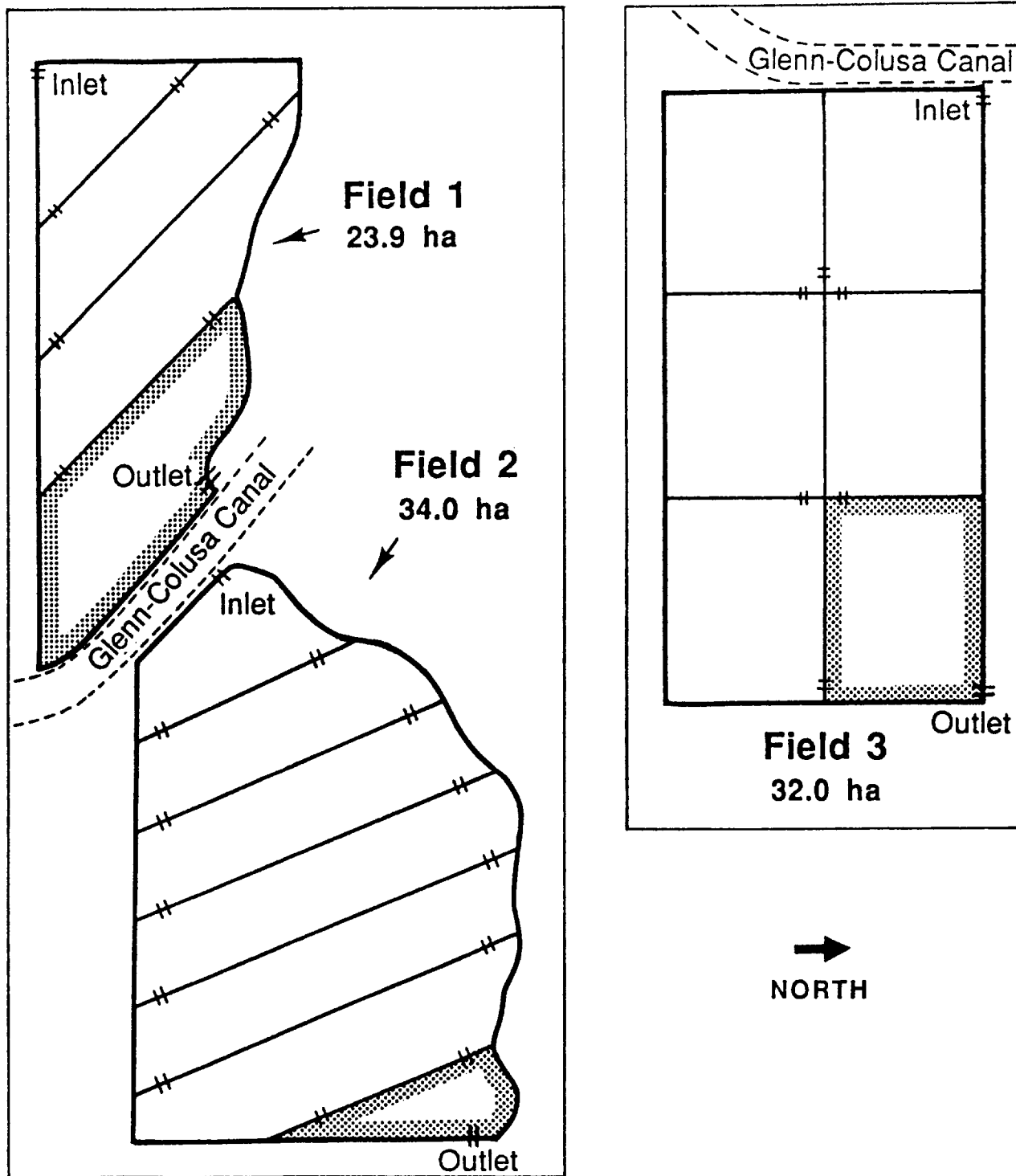


Figure 1. Fields were located adjacent to the source of irrigation water, the Glenn-Colusa Canal, in Colusa and Glenn Counties, California. Water flowed through fields via weir boxes or pipes (||) and runoff was sampled at outlets. Samples of soil and water were also collected around the perimeters of bottom paddies where carbofuran was applied (shaded areas).

readings of water height in the bottom paddy. Other measurements needed for calculation of runoff water flow rates (height of weir boards and height of water flowing over the boards) were recorded manually.

Field 1 was completely flooded 10 d after carbofuran application and was seeded the day after flooding (Table 1). Field 2 was completely flooded and was then seeded 6 d after application. Field 3 was completely flooded 4 d after application and was seeded 2 d after flooding. In general, water management varied between the three fields, but certain water management practices were related to herbicide applications. Molinate, an herbicide, was applied 11 to 14 d after flooding, and a 12 to 18 d period followed during which water was held on the fields (Table 1). Fields 2 and 3 were first drained and then treated with a second herbicide, MCPA, 39 and 43 d after flooding, respectively. Reflooding of these fields began 1 d following the MCPA application. Field 3 was treated with bentazon, another herbicide, 62 d after initial flooding, and water was held on the field for the remainder of the growing season. A summary of events is presented in Table 1.

Between 11 April and 15 July 1988, the average daily high air temperature was 28°C and low was 12°C. High and low average daily relative humidity was 90% and 37%, respectively, and average wind speeds were 1.2 to 3.7 m s<sup>-1</sup>. During the study period water depths averaged 11.0 cm, 15.1 cm, and 18.3 cm, and water temperatures averaged 22.9°C, 22.4°C, and 24.5°C in bottom paddies of Fields 1, 2, and 3, respectively.

Three sugar beet fields (Fields 4, 5 and 6) in Colusa County were selected to measure carbofuran concentrations in runoff water during the first irrigation of these fields. Fields 4, 5, and 6 were 14, 40, and 97 ha, respectively. All fields used 76 cm furrow spacing. Carbofuran was applied with seed as a 10% granular formulation, to Field 4 as 13 cm-wide bands on rows and pressed into the soil, to Field 5 as 1 cm-wide bands which were incorporated 3 cm deep, and to Field 6 in wide bands (exact width unknown) incorporated to a depth of 0.6 cm. Applications were made to Fields 4, 5, and 6 on 18 to 20 May, 10 to 22 May, and 31 May to 1 June, 1988,

Table 1. Schedule of events for three rice fields monitored for carbofuran dissipation and runoff.

Initial Events	Date (1988)		
	<u>Field 1</u>	<u>Field 2</u>	<u>Field 3</u>
Carbofuran application	16 April <sup>a</sup>	12 April <sup>a</sup>	14 April <sup>b</sup>
Initial flooding of fields	26 April	18 April	18 April

Events After Flooding	Day <sup>c</sup>		
	<u>Field 1</u>	<u>Field 2</u>	<u>Field 3</u>
Seeding	1	0	2
Molinate application	14	11	14
Molinate water holding period	14-25	11-22	12-29
MCPA application	--	39	43
Bentazon application	--	--	62

<sup>a</sup> After application, the field was rolled and carbofuran incorporated.

<sup>b</sup> Field was rolled prior to application and incorporation of carbofuran.

<sup>c</sup> Days after initial flooding of rice fields.

respectively. Irrigations began immediately after application and seeding in all 3 fields.

### **Agricultural Drains**

In addition to the monitoring conducted by CDFA, the California Department of Fish and Game (CDFG) collected and analyzed surface water samples from agricultural drains for carbofuran. Samples were collected from each of the following four locations in Colusa County: Freshwater Creek/Salt Creek near the confluence with the Colusa Basin Drain; Stone Corral Creek at Maxwell Road; Colusa Basin Drain at Colusa Wildlife Refuge (CBD5); and Willow Creek at Norman Road (Fig. 2).

### **Application Rates**

Application rates for carbofuran in rice fields were calculated from the measured weights of granules applied and areas of application. Areas of application were determined from perimeter measurements of each paddy in each field and the swath width of the application equipment. Application rates in Fields 1, 2, and 3 were 1.10, 1.21, and 0.64 kg a.i. ha<sup>-1</sup> for the whole field, and 1.10, 1.81, and 0.66 kg a.i. ha<sup>-1</sup> for the bottom paddy only, respectively (Table 2). Application rates in Fields 1 and 2 were two to three times the recommended label rate of 0.56 kg a.i. ha<sup>-1</sup>. Analysis of granule samples from each bag used on the fields were analyzed and confirmed that the actual percentage of active ingredient was 5.2 ± 0.11% (n=15). Calculations were performed based on a 5.0% formulation.

Carbofuran application rates for sugar beet fields determined from growers' records were 1.5, 1.7, and 1.1 to 1.3 kg a.i. ha<sup>-1</sup> for Fields 4, 5, and 6, respectively. These rates are close to the recommended label rate of 1.57 kg a.i. ha<sup>-1</sup> for banded and incorporated Furadan® 10G used on rows with 76.2 cm spacings.

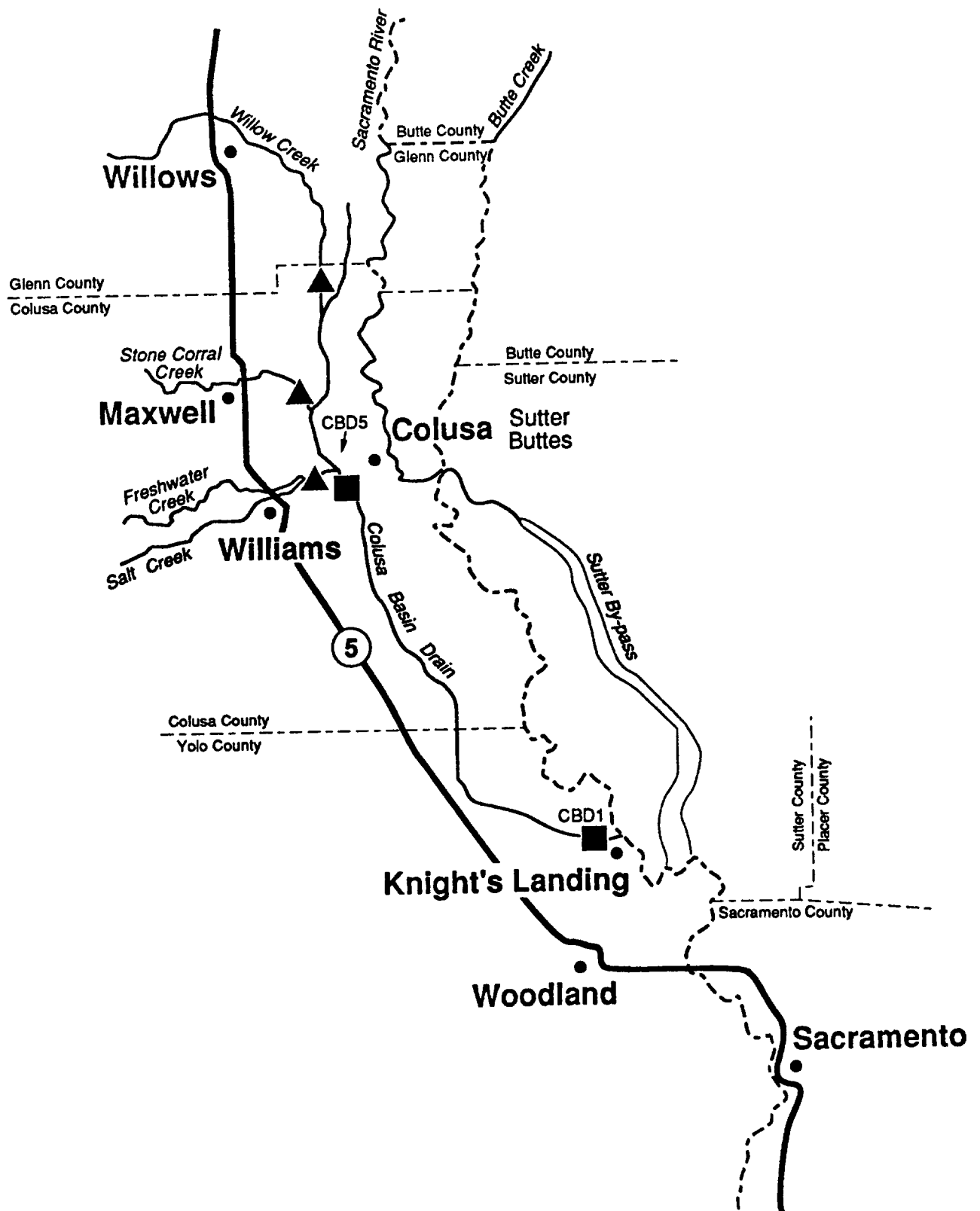


Figure 2. Agricultural drain water sampling locations along the Colusa Basin Drain (■) and its tributaries (▲) in the Sacramento Valley, California.

Table 2. Carbofuran application rates, total and treated field areas, and total amounts of carbofuran applied to three rice fields in Colusa and Glenn Counties, California.

Measurement	Field 1	Field 2	Field 3
Carbofuran application rate <sup>a</sup> (kg a.i. ha <sup>-1</sup> )			
Whole field	1.10	1.21	0.64
Bottom paddy	1.10	1.81	0.66
Total area (ha)			
Whole field	24	34	32
Bottom paddy	6.5	2.8	5.3
Treated area <sup>b</sup> (ha)			
Whole field	5.1	6.8	8.5
Bottom paddy	1.3	0.8	1.4
Total carbofuran mass applied (kg a.i.)			
Whole field	5.59	8.24	5.43
Bottom paddy	1.41	1.47	0.89

<sup>a</sup> Carbofuran recommended label rate  $\approx$  0.56 kg a.i. ha<sup>-1</sup>.

<sup>b</sup> Carbofuran was applied only to borders of the rice paddies.

## Sample Collection

### Field Runoff and Agricultural Drain Water

Runoff water samples were collected at the outlet of each rice field and analyzed for carbofuran concentrations during a three month period from mid-April to early-July. Water was sampled during periods of runoff for 72, 80 and 54 d after flooding for Fields 1, 2 and 3, respectively. Samples were collected with decreasing frequency as the study progressed. The frequency of sampling in relation to the number of days after flooding varied for each field due to differences in growers' management practices. Prior to the molinate holding period, outlet samples were collected three times per day (morning, midday and early evening) on each day that runoff water was released (Table 3). Samples were collected twice each day (morning and late afternoon) of runoff water release for approximately two weeks following the molinate holding period. Subsequently, sampling was reduced to once per day (morning) for approximately three weeks, and then two times per week, for two more weeks. Field 2 had one sample taken during the final week of the study. Periodic sampling of irrigation water at field inlets indicated that carbofuran was not present in measurable amounts in source water (detection limit =  $0.5 \mu\text{g L}^{-1}$ ).

Runoff water samples were collected from the stream of water flowing over the drain weir in 1-L amber glass bottles. Water samples were then acidified ( $\text{pH} < 3$ ) with concentrated sulfuric acid to prevent degradation of carbofuran, sealed with Teflon®-lined caps and placed immediately on wet ice; samples were stored at  $4^{\circ}\text{C}$  until analyzed. When more than one sample was taken per day, sampling times were spaced as evenly as possible throughout the day. Inlet water samples were collected in a similar manner by immersing the bottle in the stream of water entering the top paddy in each field, and stored as described above.

Irrigation runoff water was collected from sugar beet fields during the first furrow irrigations, when greatest losses of residues in runoff were expected, 3 to 5 d after carbofuran applications. Samples were collected 3 times a day (morning, midday, evening) for approximately two 24-hour

Table 3. Sampling frequency and sampling periods for measurement of carbofuran in runoff water released from three rice fields.

<u>Sampling frequency</u>	<u>Sampling period<sup>a</sup></u>		
<u>---no. samples per time---</u>	<u>-----day<sup>b</sup>-----</u>		
	<u>Field 1</u>	<u>Field 2</u>	<u>Field 3</u>
3 (per day) <sup>c</sup>	0-13	0-9	1-10
2 (per day) <sup>d</sup>	26-40	23-36	30-40
1 (per day) <sup>d</sup>	41-62	37-57	41-54
2 (per week) <sup>d</sup>	63-72	58-73	--
1 (per week) <sup>d</sup>	--	74-80	-

<sup>a</sup> During this period, sampling occurred only on days of water release.

<sup>b</sup> Days after initial flooding of rice fields.

<sup>c</sup> These samples were collected prior to molinate water holding period.

<sup>d</sup> These samples were collected after molinate water holding period.

periods. Water was sampled from the tail-water ditch by immersing a 1-L amber glass bottle into the center of the stream. Water samples were pH-adjusted, sealed, and stored as previously described. Inlet water collected once from the supply canal for Field 6 contained a low level ( $1.0 \mu\text{g L}^{-1}$ ) of carbofuran, near the detection limit ( $0.5 \mu\text{g L}^{-1}$ ).

Samples were taken from the CBD and tributary agricultural drains by submerging 500-mL amber glass bottles 15 cm below the water surface. After filling, bottles were closed with Teflon®-lined caps while submerged to avoid surface contamination. Samples were placed on ice immediately following collection and stored in refrigerators at  $4^{\circ}\text{C}$  until analysis. Replicate samples were collected on the following 6 dates: 21 April, 5 May, 19 May, 2 June, 16 June, and 30 June, 1988.

#### Dissipation from Rice Fields

Dissipation of carbofuran from soil and water of rice fields was examined by sampling treated areas in the bottom paddies of each field. Soil and water samples were collected according to the schedule in Table 4. The perimeter of each bottom paddy was divided into three sections and three replicate samples of each matrix (soil and water) were taken approximately 4.5 m from the levee edge. Each sample was a composite of three subsamples, one from a different random location in each section.

Soil samples were collected with a 4.8 cm i.d. glass cylinder pushed into the paddy soil to a depth of 7.6 cm. Soil plugs were placed in 946-mL mason jars which were sealed with foil-lined lids. Samples were placed immediately on wet ice, transferred to freezers and stored frozen at  $-8^{\circ}\text{C}$  until analyzed.

Water samples were scheduled for collection 0, 1, 2, 4, 6, 8, 12, 16, 20, 24, 28, 36, 44, 52, 60, 70, and 80 d after bottom paddies were initially flooded. Exceptions to this schedule were: Field 1 was sampled 3 d after flooding (instead of 4 d after flooding); Fields 2 and 3 were sampled 11 d after flooding (instead of 12 d after flooding); and in Fields 2 and 3 water samples were not collected 44 d after flooding. Water was collected with a

Table 4. Sampling schedule for measurement of carbofuran dissipation from soil and water of bottom rice paddies in Fields 1, 2 and 3.

Sample type	Day <sup>a</sup>
Paddy soil	0, 2, 6, 11 <sup>b</sup> , 12 <sup>c</sup> , 20, 28, 36, 44, 52, 60, 70, 80 <sup>d</sup>
Paddy water	0, 1, 2, 3 <sup>c</sup> , 4 <sup>b</sup> , 6, 8, 11 <sup>b</sup> , 12 <sup>c</sup> , 16, 20, 24, 28, 36, 44, 52, 60, 70, 80 <sup>d</sup>

<sup>a</sup> Day after initial flooding of Fields 1, 2 and 3.

<sup>b</sup> Only Fields 2 and 3 were sampled.

<sup>c</sup> Only Field 1 was sampled.

<sup>d</sup> Only Fields 1 and 2 were sampled.

glass jar attached to a 4.5 m long pole which was extended into the paddy from the bank. The jar was dipped into the paddy and water was poured into the bottles through a stainless steel funnel. Water pH was adjusted and samples were placed on wet ice until transferred to refrigerators and stored at 4°C until analyzed.

### Quality Control and Chemical Analysis

Storage stability of carbofuran in soil and water was examined and interlaboratory analyses were conducted as part of the quality control (QC) program for this study. Agricultural drain samples collected by the CDFG were not included in the QC program due to the limited number of samples collected. The CDFG laboratory method of analysis for carbofuran in agricultural drain water samples is described in Appendix I.

Field samples were extracted within 65 d after collection for soil and 28 d after collection for water. Blank soil samples were spiked with 500  $\mu\text{g kg}^{-1}$  carbofuran and stored for 70 days. Water samples were spiked with 100  $\mu\text{g L}^{-1}$  of carbofuran, acidified ( $\text{pH} < 3$ ) with concentrated sulfuric acid and stored for 64 days. No appreciable loss of carbofuran occurred over these time periods. Approximately 10% of field soil and water samples were split and analyzed for carbofuran by the primary laboratory, California Analytical Laboratories (CAL; a contract laboratory), and the QC laboratory, CDFA's laboratory. A comparison of results (Appendix II) from the two laboratories, using the SAS Means procedure (SAS Inst., 1988), showed no difference between the soil analyses. CDFA's laboratory reported carbofuran concentrations that were an average of 2.6  $\mu\text{g L}^{-1}$  (range 1 to 7  $\mu\text{g L}^{-1}$ ) lower in split water samples than those reported by CAL (paired  $t$ -test,  $n=11$ ,  $\alpha=0.01$ ). This small difference would not affect dissipation rates or relative amounts of carbofuran in runoff water determined in this study. A cause for the discrepancy was not determined.

Soil samples (50 g) were shaken 1 h with 125 mL of 0.25 N HCl to extract carbofuran residues. Celite was added and samples shaken briefly to homogenize, then samples were filtered. The filter, celite and soil were extracted again with 100 mL HCl, shaken 30 min, filtered, and rinsed 3 times

with HCl. The extracts were brought up to a final volume of 400 mL. Thirty g of sodium sulfate were added to the extracts in a separatory funnel, then samples were shaken 3 times with methylene chloride. These extracts were pooled; isooctane was added as a solvent keeper, and the solution was concentrated to approximately 4 mL by rotary evaporation. The samples were reduced and exchanged to isooctane 4 times under a stream of nitrogen to a final concentration of 1 mL. Samples were analyzed for carbofuran by gas chromatography (GC) with a Varian Model 3000 (Varian, Palo Alto, CA) equipped with a thermionic selective detector and 30-m megabore columns: either DB-5 or DB-608 (both were 0.53 mm i.d.) (J and W Scientific, Folsom, CA). Columns were operated at 160°C and injection volumes were 5  $\mu$ L. Gases used were: helium as a carrier (approximately 30 mL min<sup>-1</sup>) and make up gas (approximately 25 mL min<sup>-1</sup>), and hydrogen as a detector gas (approximately 4.5 mL min<sup>-1</sup>). Detector and injector temperatures were 300°C and 220°C, respectively. Mean recoveries from soil were 94  $\pm$  12% (n = 23).

Water samples (500 mL) were combined with 10 mL concentrated HCl and 30 g NaCl in a separatory funnel. Samples were extracted 3 times with 60 mL methylene chloride. These extracts were combined, 5 mL isooctane was added as a solvent keeper, and samples were concentrated by rotary evaporation to approximately 4 mL. Extracts were reduced under nitrogen and exchanged 5 times to isooctane; final volume was 1 mL. This extraction procedure was suitable for residue levels below 200  $\mu$ g mL<sup>-1</sup>. Samples were analyzed by GC as described above. Mean recoveries from water were 95  $\pm$  14% (n = 58).

### Calculations

The mass of carbofuran discharged from rice fields was determined by a series of five interpolation and calculation steps. First, concentrations of carbofuran in runoff water were assigned to discrete periods of time over the duration of the study by interpolation of measured carbofuran concentrations. Carbofuran concentrations in runoff water were measured daily (during water release) during the beginning of the study, then tapered off to weekly and biweekly samples (Table 3). On some days, three samples of runoff concentrations were taken and on other days no samples were taken.

Because of this uneven distribution of samples over time, concentrations on all days of runoff were derived by interpolation of measured values by the following method. A given measured concentration was assigned to the time period halfway before and halfway after the measured sample. For example, a carbofuran concentration measured at 0930 h on 0 d after flooding would be assumed constant from 0000 h (when the field was initially flooded and runoff began) to halfway between the 0930 h sample and the next sample. If the second sample was taken at 1600 h on the same day, then the measured concentration would be assumed constant from 1245 h to halfway between 1600 h and the next sample. The calculations involved are: from 0930 to 1600 is 6.5 h;  $6.5 \text{ h} / 2 = 3.25 \text{ h}$ ; and  $0930 + 3.25 \text{ h}$  is 1245. Therefore, the first measured carbofuran concentration would be assumed constant for a time period of 12.75 h on 0 days after flooding (0000 to 0930 is 9.5 h; 0930 to 1245 is 3.25 h;  $9.5 \text{ h} + 3.25 \text{ h} = 12.75 \text{ h}$ ). The last measured carbofuran concentration before runoff stopped was assumed constant from the time of measurement until the end of runoff release. When runoff began again, the first measured carbofuran concentration was assumed constant for the period of time from the beginning of runoff release until halfway between the first sample and the next sample, as described above.

Second, the volume of runoff water (L) released from rice fields was calculated as the product of flow rate ( $\text{L h}^{-1}$ ) and length of time (h) water was released at a given flow rate. Flow rates were calculated using methods for broad- and sharp-crested weirs (Hulsing, 1967), and field measurements of water height over weirs and weir board heights and widths. Third, carbofuran mass (kg) discharged from rice fields was calculated as the product of concentration in runoff water ( $\text{kg L}^{-1}$ ) and the volume of water (L) released during a given time period (h). Time periods varied to coincide with halfway points between sampling of carbofuran in runoff water (discussed above) and changes in flow rates occurring within and between 24-h (daily) periods (Appendix III, Part A). A conceptual diagram for time period determination is given below:

Concentration (C)     | \_\_\_\_\_ C1 \_\_\_\_\_ |     C2     |     C3     |

Flow (F)               | \_\_\_\_\_ F1 \_\_\_\_\_ |     F2     |

Time period (T)       | \_\_\_\_\_ T1 \_\_\_\_\_ | T2 |     T3     |     T4     |

<----- 24 h ----->

Fourth, both daily volume of runoff water and daily mass of carbofuran were calculated by summing the time weighted values for each of these variables, volume and mass, by day after flooding (Appendix III, Part B). An example from Appendix III (Parts A and B) is given below:

Field	Day after flood- ing	Flow	Time	Water	Carbo- furan concen- tration	Mass
		rate (L h <sup>-1</sup> )	period (h)	volume (L)	(kg L <sup>-1</sup> )	discharged (kg)
2	0	16311	11.00	179416	0.0000000052	0.0009330
	0	63203	1.75	110606	0.0000000052	0.0005750
	0	63203	6.25	395021	0.0000000213	0.0084140
	0	63203	5.00	316017	0.0000000067	0.0021170
			-----	-----		-----
Daily totals			24.00	1001059		0.0120394

Fifth, the daily average carbofuran concentration (kg L<sup>-1</sup>) was calculated by dividing the daily mass discharged (kg) by the daily volume of water released (L). When multiplied by the conversion factor 1 x 10<sup>-9</sup> kg µg<sup>-1</sup>, daily average carbofuran concentration can also be expressed in units of

$\mu\text{g L}^{-1}$ . For days with multiple concentration or flow measurements the daily value represents a weighted average as described above. On some days, only one value was available for measured and/or interpolated runoff water concentrations and for flow.

Potential carbofuran discharge values for rice and sugar beet (P, Eq. [1]) were calculated by multiplying the fraction of applied carbofuran discharged in runoff water from a field, by the total mass applied in Glenn, Colusa and Yolo Counties during April to June, 1988:

$$P = (C_d/C_a) C_t \quad [1]$$

P = potential discharge of carbofuran mass (kg) in agricultural drains;

$C_d$  = carbofuran (kg) discharged from a field;

$C_a$  = carbofuran (kg) applied to a field;

$C_t$  = total carbofuran (kg) applied in Colusa, Glenn and Yolo Counties  
(data from County Agricultural Commissioners).

Estimates of the amount of carbofuran (kg) discharged from rice fields were derived from measurements taken during this study. Values for the amount of carbofuran (kg) discharged from sugar beet fields ( $C_{d \cdot sb}$ , Eq. [2]) were estimated from measurements of carbofuran concentrations in grab samples of runoff water from three beet fields (Appendix IV), and from an assumed volume of water discharged:

$$C_{d \cdot sb} = C_r VC \quad [2]$$

$C_{d \cdot sb}$  = carbofuran (kg) discharged from sugar beet fields;

$C_r$  = carbofuran concentration ( $\mu\text{g L}^{-1}$ ) measured in runoff water  
from sugar beet fields;

V = volume (L) of runoff water from sugar beet fields (assumed equal to the average volume of runoff measured by Spencer et al. (1985));

C =  $10^{-9}$  (kg  $\mu\text{g}^{-1}$ ) conversion factor.

Measurements of the volume of runoff water were not made for sugar beet fields. For comparison purposes, the volume of runoff water discharged from sugar beet fields (V, Eq. [2]) was assumed to equal an average volume calculated from measurements of runoff water reported by Spencer et al. (1985). In that study, the volume of irrigation runoff water was monitored for two furrow-irrigated sugar beet fields in Imperial Valley, California, during the 1978-79 and/or 1979-80 crop year.

Carbofuran mass (kg and kg  $\text{ha}^{-1}$ ) calculations were based upon concentrations measured in bottom paddy soil and water, and corresponding areas. For soil, calculations were based upon the border area of application (Treated area, Table 2). For water, calculations were based upon the entire area (Total area, Table 2). The assumption was made that little or no lateral movement, or adsorption, occurred in soil outside of the applied area. On the other hand, carbofuran was assumed to spread over the entire paddy area in water, due to mixing and diffusion.

## RESULTS AND DISCUSSION

### Mass Discharged from Rice

The total number of days that water was released from fields, during the 80 d sampling period, ranged from 34 to 65 days (Table 5). The pattern of individual days of water release varied for each field. During the first 30 d period after flooding there were relatively few days when water was released from Field 1. In addition, during this period molinate (an herbicide) was applied and water was held on the fields for the following 12 to 18 d. After the holding period for molinate (which allows time for dissipation of this herbicide on-field), water was released almost continuously for the remainder of the study, except in Field 3. Field 3 was boarded up 54 d after flooding for application of bentazon (an herbicide) and water was held on this field for the rest of the study. Although Field 3 had the fewest number of days of water discharge (34 d), the greatest total volume of water ( $151.82 \times 10^6$  L) was released from this field. Total volumes of water released over the 54 to 80 d period ( $80.40$  to  $151.82 \times 10^6$  L) were greater than the findings of McGill (1982) for two rice fields (27 and  $72 \times 10^6$  L during the first 69 and 46 d of water release, respectively) located in Colusa and Glenn Counties.

The percent of applied carbofuran discharged in runoff water over the study period totaled 1.72, 5.40 and 11.03% for Fields 1, 2, and 3, respectively (Table 6). The average percent of applied carbofuran discharged in runoff water from these fields was 6.05% over an 80 d period. Comparable carbofuran runoff data for rice fields do not exist in the literature; however, in comparison with other rice pesticides the 6.05% of applied carbofuran discharged was approximately one-half of the average percents of applied molinate (11%,  $n = 9$ ) and thiobencarb (14.2%,  $n = 5$ ) discharged in runoff water from rice fields within one month after application (Ross et al., 1984).

Runoff loads, the ratio of total carbofuran mass discharged in runoff water to the total volume of runoff water released, were calculated for each of three time periods (Table 7). The greatest runoff loads consistently

Table 5. Calculated volume of runoff water and number of days runoff water was released from three rice fields in Colusa and Glenn Counties, California, 1988.

Time Period	Field 1	Field 2	Field 3
--day <sup>a</sup> --	----- runoff water <sup>b</sup> L x 10 <sup>6</sup> (no. days runoff) -----		
0-30	3.95 (6)	28.80 (17)	20.19 (12)
31-60	42.17 (28)	47.10 (28)	131.63 (22)
61-80	34.28 (12)	24.12 (20)	----- <sup>c</sup>
Total	80.40 (46)	100.02 (65)	151.82 (34)

<sup>a</sup> Days after initial flooding of rice fields.

<sup>b</sup> Daily volume was product of number of hours of runoff (h) and flow rate (L h<sup>-1</sup>); this was summed for each month.

<sup>c</sup> No runoff; water was held on Field 3 from 54 d after flooding until harvest, due to bentazon application.

Table 6. Calculated carbofuran mass discharged in runoff water and percent of applied carbofuran moved off-field in runoff water from three rice fields in Colusa and Glenn Counties, California, 1988.

Time Period	Field 1	Field 2	Field 3
--day <sup>a</sup> --	----- carbofuran <sup>b</sup> kg a.i. (% of applied <sup>c</sup> ) -----		
0-30	0.027 (0.49)	0.354 (4.30)	0.215 (3.97)
31-60	0.045 (0.81)	0.064 (0.77)	0.384 (7.06)
61-80	0.024 (0.43)	0.027 (0.33)	----- <sup>d</sup>
Total	0.096 (1.72)	0.445 (5.40)	0.599 (11.03)

<sup>a</sup> Days after initial flooding in rice fields.

<sup>b</sup> Daily carbofuran mass discharged in runoff water was calculated as the product of the carbofuran concentration ( $\text{kg L}^{-1}$ ) and the volume of runoff water (L); this mass was summed over each month.

<sup>c</sup> Mass of carbofuran applied to entire field was 5.59, 8.24 and 5.43 kg a.i. for Fields 1, 2 and 3, respectively.

<sup>d</sup> No runoff; water was held on Field 3 from 54 d after flooding, until harvest, due to bentazon application.

Table 7. Runoff loads for carbofuran discharged in runoff water from three rice fields for three time periods after initial flooding.

Time Period	Field 1	Field 2	Field 3
--day <sup>a</sup> --	---- runoff load <sup>b</sup> , carbofuran kg L <sup>-1</sup> x 10 <sup>-9</sup> ----		
0-30	6.84	12.29	10.65
31-60	1.07	1.36	2.92
61-80	0.70	1.12	--- <sup>c</sup>

<sup>a</sup> Days after initial flooding in rice fields.

<sup>b</sup> Runoff loads (kg L<sup>-1</sup> x 10<sup>-9</sup>) are quotients of the mass of carbofuran discharged (kg) divided by the volume of runoff water (L), for each of the three time periods.

<sup>c</sup> No runoff; water was held on Field 3 from 54 d after flooding until harvest, due to bentazon application.

occurred during the first 30 d period after flooding, for all three fields . Runoff loads decreased in subsequent time periods. The high runoff loads during the first 30 d after flooding were consistent with the findings of Haith (1987). He determined from simulation modeling that the runoff loads of carbofuran from surface applications to soil in corn fields would be greatest during the month of application.

Mass discharge is a function of both the concentration of carbofuran in runoff water and the volume of water released. Although runoff loads decreased greatly after the first 30 d period, the amount of mass discharged (Table 6 and Fig. 3) was greatest during the period 31 to 60 d after flooding, in Fields 1 and 3. This was due to the greater volume of water released from these fields over more days during this period (Table 5 and Fig. 4). The greatest mass discharge of carbofuran from Field 2 occurred during the first 30 d after flooding. This was due to the movement off-field of approximately 0.2 kg of carbofuran (44% of the total carbofuran mass discharged) within three consecutive days soon after the molinate holding period (24 to 26 d after flooding) (Fig. 3). During this period, a combination of high daily average concentrations of carbofuran in runoff water ( $22$  to  $28 \mu\text{g L}^{-1}$ ) and large volumes of water released ( $2.10$  to  $3.21 \times 10^6$  L) (Fig. 4) resulted in the large mass of carbofuran moving off-field. These three days demonstrate the effect that daily mass discharges can have on the total mass of carbofuran released off-field. Large carbofuran mass discharges were not always the result of high concentrations coupled with large releases of runoff water. Approximately 9 to 10% of the total carbofuran mass discharged was released from Field 1 ( $0.9$  to  $1.0 \text{ kg} \times 10^{-2}$  carbofuran) on both 0 and 32 d after flooding and from Field 3 ( $5.7$  to  $6.1 \times 10^{-2}$  kg carbofuran) on both 32 and 33 d after flooding (Fig. 3). This occurred when daily average concentrations of carbofuran were low to moderate ( $4.2$  to  $6.8 \mu\text{g L}^{-1}$ ) and water volumes released were large ( $1.57$  to  $9.18 \times 10^6$  L) (Fig. 4).

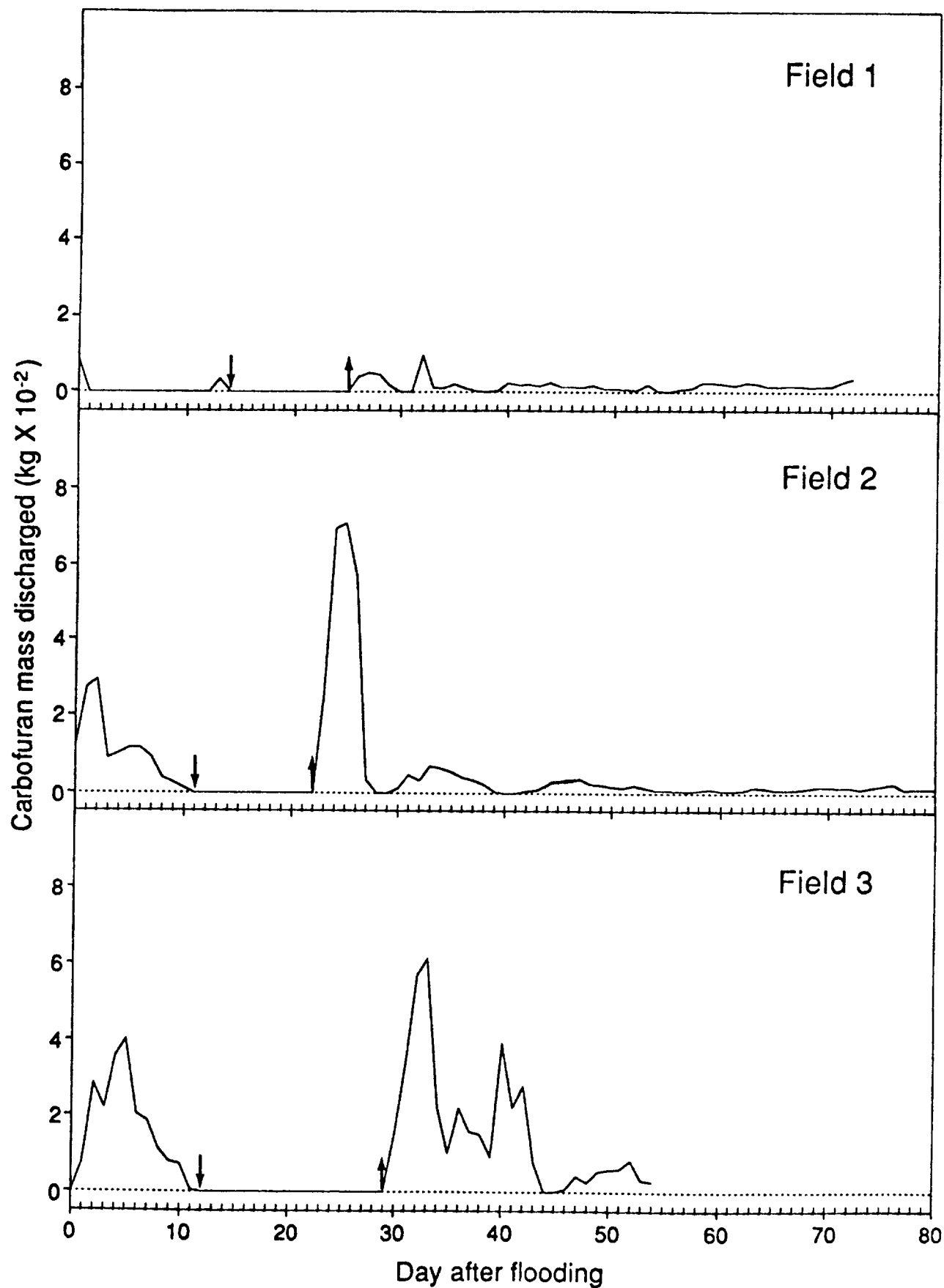


Figure 3. Daily mass of carbofuran discharged, after initial flooding, in runoff water from three rice fields. Arrows indicate beginning (↓) and ending (↑) points of the water holding period for molinate applications.

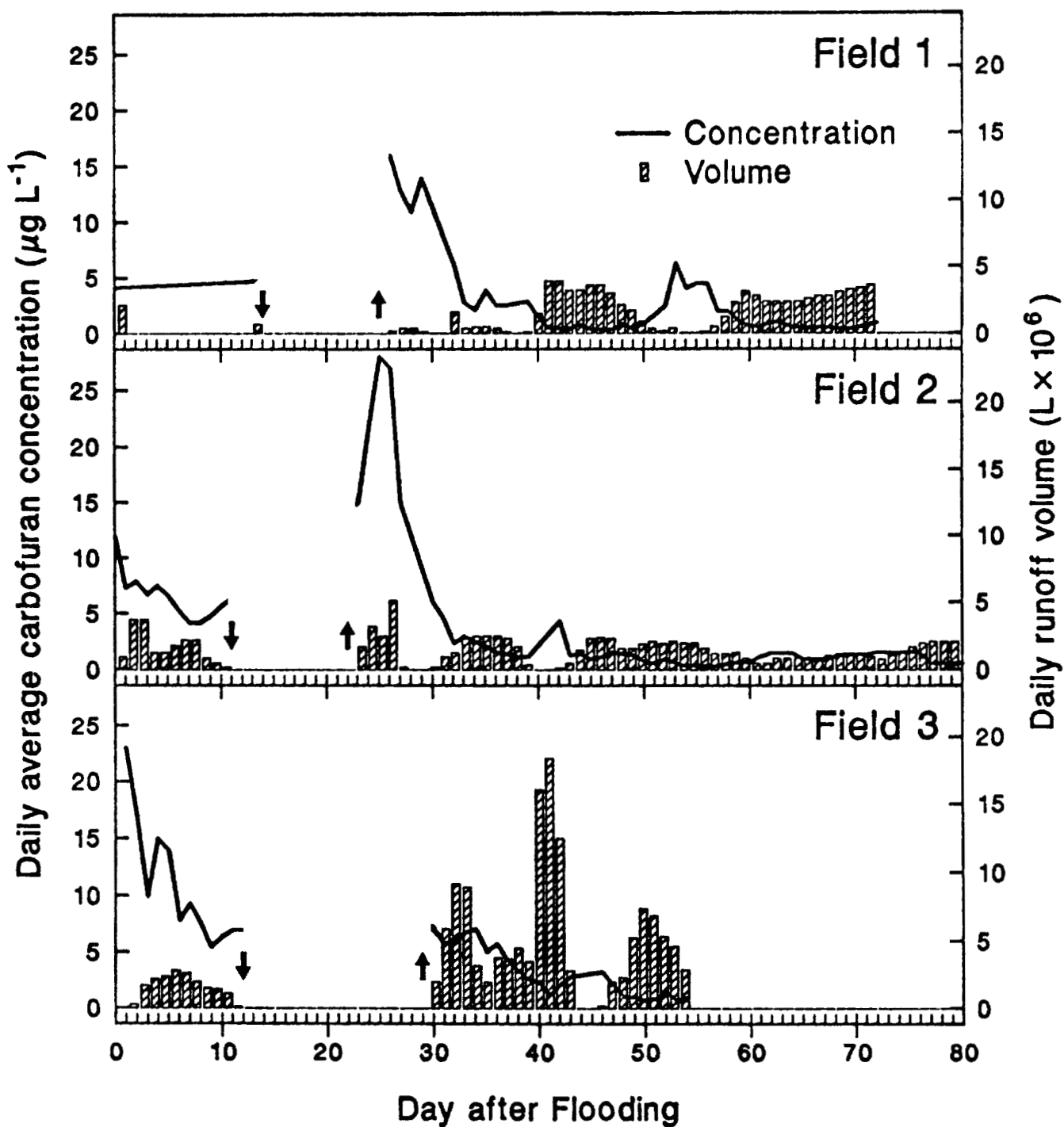


Figure 4. Daily average carbofuran concentrations and daily volume of runoff water released from three rice fields, after initial flooding. Arrows indicate beginning ( $\downarrow$ ) and ending ( $\uparrow$ ) points of the water holding period for molinate applications.

Maximum concentrations of carbofuran in runoff water from all fields ranged from 21 to 33  $\mu\text{g L}^{-1}$  and occurred within 26 d after flooding (Table 8). In Fields 1 and 2, maximum carbofuran concentrations occurred in runoff water released following the molinate holding period (26, and 24 to 26 d after flooding, respectively). Maximum carbofuran concentrations in Field 3 runoff water occurred 1 d after flooding, prior to the molinate holding period, on the first day of water release. The reasons for maximum carbofuran concentrations occurring before or after the molinate holding period are unknown and cannot be determined by this study, but in some cases may have been related to low water levels in the fields. Concentrations in runoff water declined with time and generally remained below 5  $\mu\text{g L}^{-1}$  by 43 d after flooding in all fields.

#### **Rice vs. Sugar Beet**

Average concentrations of carbofuran in runoff water from three sugar beet fields sampled during their first irrigations were generally higher than the early season concentrations from rice runoff. Average and maximum concentrations for Fields 4, 5 and 6 were  $25 \pm 12$  and 45,  $1 \pm 1$  and 4, and  $134 \pm 49$  and 200  $\mu\text{g L}^{-1}$ , respectively (Appendix IV).

Information was obtained from County Agricultural Commissioners on carbofuran use in Colusa, Glenn and Yolo Counties and used to calculate potential mass discharged from rice and sugar beet fields from April through July, 1988. The total amount of carbofuran active ingredient applied in the three counties was 7,619 kg for rice and 967 kg for sugar beet fields. Approximately 461 kg of carbofuran from rice fields and 41 kg from sugar beet fields were hypothetically discharged into agricultural drains in 1988 (Appendix V, Parts A and B). It should be noted that these values were derived from only three rice fields (in Colusa and Glenn Counties only) and from grab samples from three sugar beet fields (in Colusa County only). Therefore, these estimates of potential carbofuran mass discharged may not be entirely representative of rice and sugar beet fields in Colusa, Glenn and Yolo Counties. Concentrations measured from these rice fields, where carbofuran was incorporated into the soil, were low (maximum concentration =

Table 8. Concentrations and days of maximum carbofuran residues in runoff water from three rice fields, and days water was held on fields due to molinate application.

Field	Max. carbofuran residues		Molinate holding period
	-- $\mu\text{g L}^{-1}$ --	-- day <sup>a</sup> --	----- day <sup>a</sup> -----
1	21.1	26	14 - 25
2	32.8	24-26	11 - 22
3	27.1	1	12 - 29

<sup>a</sup> Days after initial flooding of rice fields.

33  $\mu\text{g L}^{-1}$ ) compared with concentrations resulting from a non-incorporated application. Deuel et al. (1979) found maximum concentrations of carbofuran in rice paddy water at approximately 200 to 300  $\mu\text{g L}^{-1}$  when granules were applied to standing water at a rate of 0.56 kg a.i.  $\text{ha}^{-1}$ . Therefore, the calculated potential discharge for rice, which was based on incorporated carbofuran applications, may be low. Also, in calculating these values for sugar beet fields, the volume of water discharged was assumed to equal an average volume ( $1.0 \times 10^6 \text{ L ha}^{-1}$ , over four irrigations) calculated from measurements of runoff water reported by Spencer et al. (1985). This assumption is reasonable; but even if the volumes of water released from sugar beet fields were doubled, the ratio of carbofuran mass discharged from rice to sugar beet would only be reduced from 11:1 (461:41 kg) to 6:1 (461:82 kg). These estimates indicate that the potential discharge of carbofuran in agricultural runoff water is greater from rice than sugar beet fields in this three-county area.

To further support the case that the major portion of carbofuran residues in agricultural drains came from rice fields, information on carbofuran use (described above) was compared with concentrations of carbofuran found in Colusa Basin Drain (CBD) water samples collected by the CDFG. These samples were collected as part of an ongoing program to monitor surface waters for residues of pesticides used in rice fields (CDFA, 1988). Figure 5 shows that the highest concentrations of carbofuran were found in drain water at the CBD1 site during the end of April and the first half of May. Very little carbofuran was applied to sugar beet fields during this time period in comparison with rice. Warm weather occurred in the beginning of April in 1988, prompting rice growers to get an early start. In addition, the largest amounts of carbofuran applied to sugar beet fields during this time period were in Yolo County where a small percentage of the agricultural water drains into the CBD. As a part of this study, water samples were collected from four additional sites along agricultural drains in Colusa County. Concentrations of carbofuran in water at these locations support the levels found at the CBD1 site (Fig. 6) and indicate that sources for

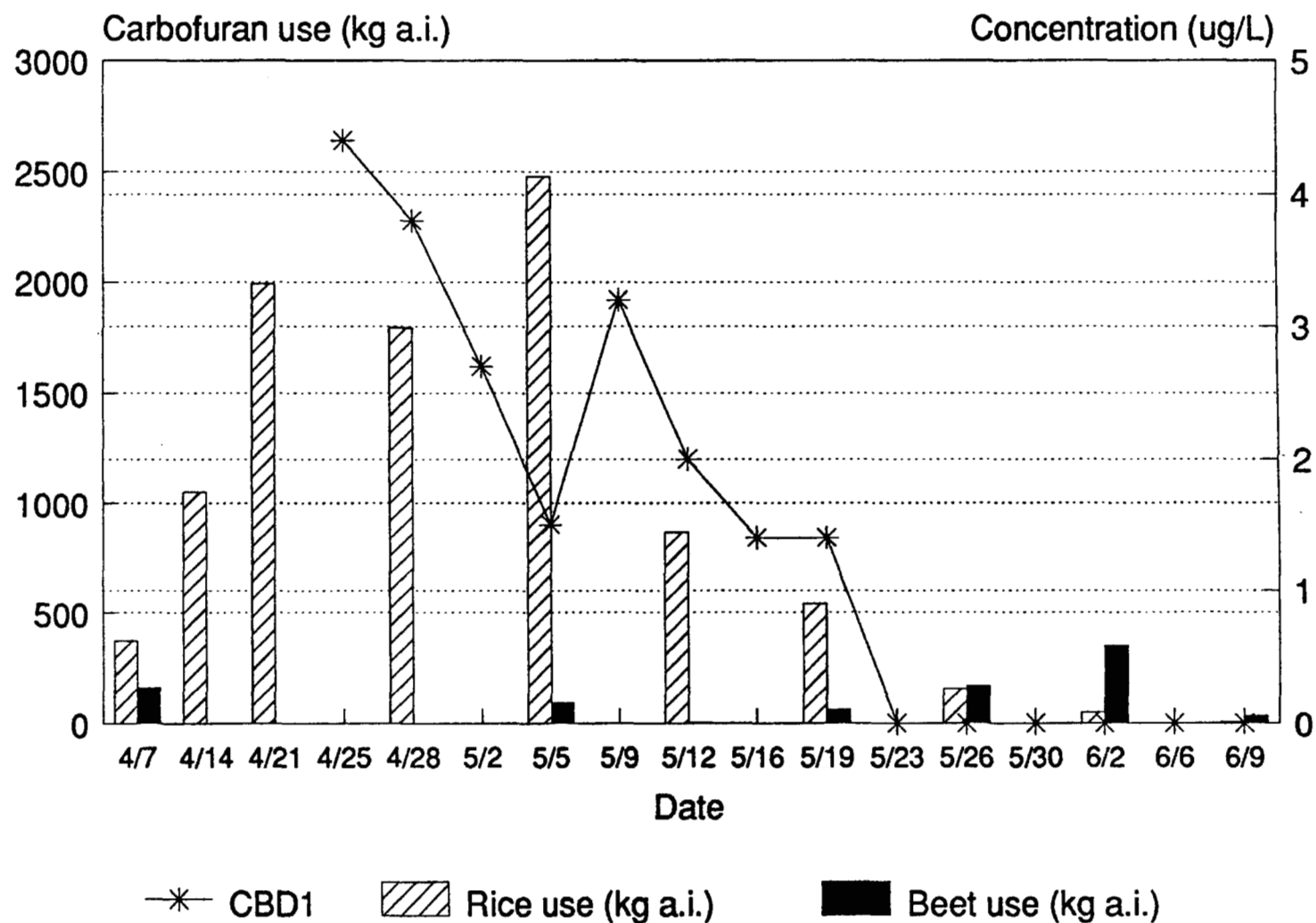


Figure 5. Total mass of carbofuran used per week in Colusa, Glenn and Yolo Counties vs. concentrations of carbofuran in water (detection limit  $1.0 \mu\text{g L}^{-1}$ ) at the CBD1 agricultural drain site in Yolo County, California, 1988.

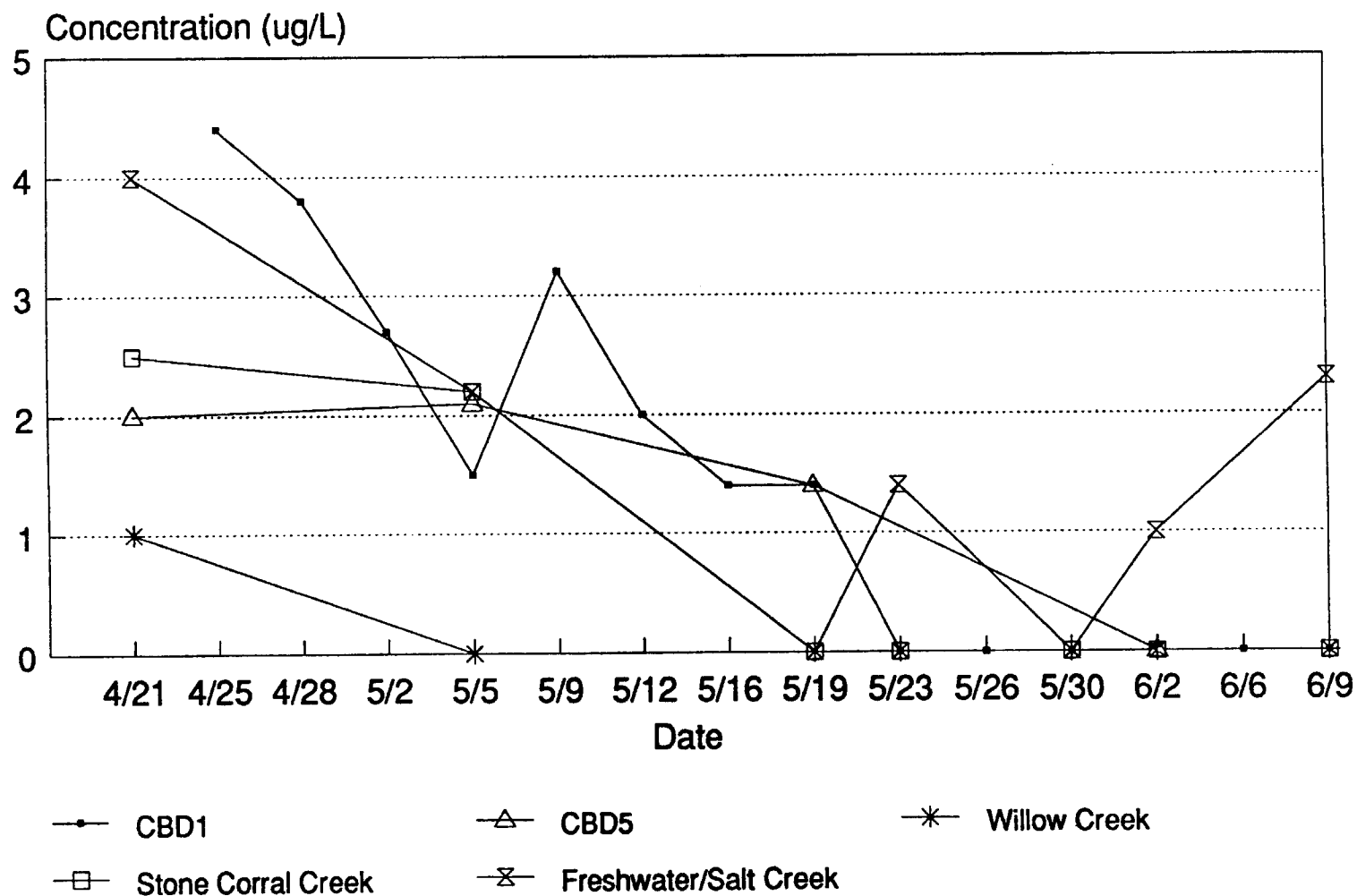


Figure 6. Carbofuran water concentrations (detection limit  $1.0 \mu\text{g L}^{-1}$ ) found at agricultural drain sampling sites in Colusa and Yolo Counties, California, 1988.

most of the residues were north of Yolo County where the majority of carbofuran use is in rice fields.

#### Dissipation from Paddy Soil and Water

Concentrations of carbofuran in paddy soil were quite variable (average coefficient of variation within day was 38%) in all three fields, but generally declined over the 80 d sampling period in Fields 1 and 2. Concentrations did not decline appreciably in Field 3 during 70 d of sampling. Variability was due to the uneven distribution of granules incorporated into the soil (Taylor et al., 1985). Maximum average (n=3) concentrations of carbofuran in paddy soil ranged from 0.50 to 0.79 mg kg<sup>-1</sup> and occurred within 11 to 20 d after flooding the fields. Final average concentrations in soil were 0.15, 0.19 and 0.57 mg kg<sup>-1</sup> in Fields 1, 2 and 3, respectively (Table 9).

Dissipation of the mass of carbofuran in paddy soil in Fields 1 and 2 was a log-linear function of time. Dissipation half-lives in soil were determined to be 58 and 43 d after flooding in Field 1 and Field 2, respectively (Table 10). Regression analysis indicated that dissipation in Field 3 was not significant ( $F = 0.44$ ;  $df = 1,9$ ;  $P > 0.5$ ) over the 70 day sampling period; therefore, the best predictor of carbofuran mass in soil for Field 3 on any day during the study was the overall mean of 0.50 kg ha<sup>-1</sup>. Degradation within the zone of sampling or movement of carbofuran mass out of that zone, by leaching or by diffusion into paddy water, may have contributed to the dissipation process. Soil pH can affect the hydrolytic degradation rate of carbofuran (Caro et al., 1973; Getzin, 1973). Since soil pH was similar in all of the fields (average pH = 6.2, 5.8 and 6.31 in Fields 1, 2 and 3, respectively), persistence of carbofuran in Field 3 soil indicated that degradation by hydrolysis was not an important factor in the dissipation process. This may have been due to low pH levels. Deuel et al. (1979) determined that hydrolysis was not a major contributing factor in the dissipation of carbofuran from rice paddy water (pH 6.0 to 6.5). These half-lives should be taken as an approximation of dissipation, since the data were variable and the models were only able to explain 61 to 68% of the variation (Table 10).

Table 9. Maximum average ( $n = 3$ ) concentrations of carbofuran found after flooding rice fields and final average ( $n = 3$ ) concentrations found in soil and water of bottom paddies of three rice fields.

	SOIL		WATER	
	Max. avg. conc. ----- mg kg <sup>-1</sup> (day) <sup>a</sup>	Final avg. conc. -----	Max. avg. conc. ----- μg L <sup>-1</sup> (day) <sup>a</sup>	Final avg. conc. -----
Field 1	0.50 (12)	0.15 (80)	38.2 (20)	1.2 (80)
Field 2	0.80 (20)	0.19 (80)	24.8 (28)	0.7 (80)
Field 3	0.79 (11)	0.57 (70)	24.5 (1)	1.7 (70)

<sup>a</sup> Days after initial flooding of the field.

Table 10. Regression analyses of carbofuran dissipation in paddy soil and water and calculated half-lives.

	Model <sup>a</sup>	R <sup>2</sup>	Calc. <sup>b</sup> half- life (day) <sup>c</sup>
<u>SOIL</u>			
Field 1	y= -0.80 - 0.012 (day) <sup>c</sup>	0.61	58
Field 2	y= -0.43 - 0.016 (day)	0.68	43
Field 3	y= -0.62 - 0.002 (day)	0.05 <sup>d</sup>	-- <sup>e</sup>
<u>WATER</u>			
Field 1	y= -4.03 - 0.031 (day)	0.73	22
Field 2	y= -4.23 - 0.027 (day)	0.73	26
Field 3	y= -3.39 - 0.039 (day)	0.77	18

<sup>a</sup> Dependent variable (y) = ln [avg. carbofuran mass per unit area (kg ha<sup>-1</sup>)].

<sup>b</sup> Half-life calculated by:  $t_{1/2} = \frac{\ln 2}{|b_1|}$ ; b<sub>1</sub>= regression slope; n = 11 to 17.

<sup>c</sup> Day= days after initial flooding of the field.

<sup>d</sup> Regression model was not significant (F= 0.44; df= 1,9; P > 0.5)

<sup>e</sup> Half-life not calculated; dissipation not significant over study period.

Carbofuran soil half-lives for Fields 1 and 2 were considerably shorter than the half-life determined by Caro et al. (1973) for carbofuran granules incorporated ( $4.61 \text{ kg a.i. ha}^{-1}$ ) in seed-furrows of a corn field (half-life = 117 d after application). Low soil pH (5.2) and low soil moisture content (compared with flooded soil), which promote stability of carbofuran, may have been contributing factors in his study.

Carbofuran concentrations fluctuated widely in paddy water early in the study, but variability within day (average coefficient of variation = 18%) was less in water than in paddy soil. Maximum average ( $n = 3$ ) concentrations of carbofuran in paddy water ranged from  $24.5$  to  $38.2 \mu\text{g L}^{-1}$  within 1 to 28 d after flooding the fields. These concentrations were low compared with maximum water concentrations of approximately 200 to  $300 \mu\text{g L}^{-1}$  reported by Deuel et al. (1979) for carbofuran applied directly to paddy water. Final average concentrations of carbofuran in water were 1.2, 0.7 and  $1.7 \mu\text{g L}^{-1}$  in Fields 1, 2 and 3, respectively (Table 9).

Dissipation of carbofuran mass in paddy water was similar for all three fields. Regression analyses indicated that dissipation of carbofuran mass in water was a log-linear function of days after flooding the fields. Water dissipation half-lives calculated from regression curves ranged from 18 to 26 d after flooding (Table 10). Shorter dissipation times were reported by Deuel et al. (1979) for a rice field in Texas. He found that granular carbofuran applied at the recommended rate ( $0.56 \text{ kg a.i. ha}^{-1}$ ) to paddy water generally dissipated within four days. In the Philippines, Siddaramappa et al. (1978) found that broadcast applications of granular carbofuran ( $2 \text{ kg a.i. ha}^{-1}$ ) to paddy water resulted in hydrolysis of carbofuran to carbofuran phenol within five days.

Although significant dissipation of carbofuran in soil was not observed in Field 3, this did not influence the dissipation of carbofuran in paddy water. This may have been due to higher pH levels in water (average pH 7.0 to 7.6) than in soil (average pH 5.8 to 6.3) which increased rates of carbofuran degradation by hydrolysis (Seiber, 1978).

### Mass Recovered from Paddy Soil and Water

The mass of carbofuran recovered in paddy soil 0 d after flooding was 44, 32 and 109% of the mass applied in Fields 1, 2 and 3, respectively (Table 11). Recoveries of carbofuran mass in paddy soil over 100% occurred due to the variable distribution of granules and extrapolation of sample mass recovered to the entire treated paddy area. Low recovery occurred despite the high rates of application in Fields 1 and 2 (1.10 and 1.81 kg a.i. ha<sup>-1</sup>, respectively) compared with Field 3 (0.66 kg a.i. ha<sup>-1</sup>). This may be due to the difference in final preparation of the fields. Fields 1 and 2 were "rolled" to create ridges in the seed bed (to prevent seeds from moving to field edges) and to pack and seal the soil surface which prevents loose soil from covering the seeds during periods of rough water. Since "rolling" occurred after application of the carbofuran granules, a surface layer of soil may have been formed which trapped granules below it and acted as a barrier to upward diffusion of carbofuran. The soil in Field 3 was "rolled" before application and this may have helped to retain the carbofuran granules in the surface layer. Carbofuran granules are stable in soil under low moisture conditions (Harris et al., 1988) which existed in Fields 1 and 2 (approximately 18% soil moisture) prior to flooding. It is unlikely that 50% or more of the carbofuran in Fields 1 and 2 would have degraded within six to 10 days after application. An alternative explanation is that some of the carbofuran was unavailable for sampling because granules had moved below the 7.6 cm sampling depth during or after application, before the fields were flooded.

Carbofuran mass recovered in paddy water was considerably less than the mass recovered in soil throughout the study for all fields. In Field 3, the mass recovered in water 0 d after flooding was relatively high compared with Fields 1 and 2 (Table 11), reflecting the maximum concentrations found in runoff and paddy water in Field 3, 1 d after flooding. By 70 d after flooding the mass recovered in paddy water was less than 1% of the total mass applied, for all fields. The total mass of carbofuran in soil and water of the bottom paddies of the fields 0 d after flooding ranged from 34 to 132% of the mass applied. Seventy d after flooding the total mass of carbofuran recovered from soil and water ranged from 18 to 89% of the mass

Table 11. Carbofuran mass and percent of applied carbofuran recovered from soil and water in bottom paddies of rice fields. Total mass recovered from soil and water as percent of carbofuran mass applied.

	SOIL		WATER		TOTAL
	% of		% of		% OF
	kg	applied	kg	applied	APPLIED <sup>a</sup>
<u>0 Days after flooding</u>					
Field 1	0.62	44	0.083	6	50
Field 2	0.47	32	0.036	2	34
Field 3	0.97	109 <sup>b</sup>	0.200	23	132 <sup>b</sup>
<u>70 Days after flooding</u>					
Field 1	0.29	21	0.011	0.8	22
Field 2	0.26	18	0.006	0.4	18
Field 3	0.78	88	0.008	0.9	89

<sup>a</sup> Total mass of carbofuran applied to bottom paddies of Fields 1, 2 and 3 was 1.41, 1.47 and 0.89 kg, respectively.

<sup>b</sup> Recoveries of carbofuran mass in paddy soil over 100% were due to variable distribution of granules in soil and extrapolation of sample mass to the entire treated area.

applied. The average mass of carbofuran in paddy water alone on any day during the study did not exceed 27% of the mass applied. The majority of the carbofuran mass incorporated into the soil remained there throughout the study with relatively small amounts diffusing out into the water and transported off-field.

Carbofuran has a relatively high water solubility,  $291 \text{ mg L}^{-1}$  at  $10^\circ\text{C}$  to  $700 \text{ mg L}^{-1}$  at  $25^\circ\text{C}$  (Bowman and Sans, 1985; Kuhr and Dorough, 1976), and adsorption in clay loam soil is relatively low,  $K_d$  0.25 to  $2.22 \text{ mL g}^{-1}$  (Felsot and Wilson, 1980; Kumari et al., 1988). This suggests that carbofuran may partition to a great extent into the water component. This was not seen when carbofuran was soil-incorporated. The mass recovered in paddy soil was five or more times the mass recovered in water, 0 d after flooding (Table 11). The mass in water decreased over time until the mass in soil was up to 98 times greater than the mass in water, by 70 d after flooding. The low levels of carbofuran in water may have been due in part to the general downward percolation of water through the soil, leaving transfer of carbofuran upward to the slower process of diffusion. As rice plants developed, uptake of carbofuran through their roots may also have reduced the movement upward. Additionally, concentrations in paddy water were affected by dilution from irrigation water and off-field transport. Siddaramappa and Seiber (1979) reported increased persistence in soil and lower concentrations in standing water, in a laboratory model ecosystem, when carbofuran was applied as a solution injected to a depth of three cm below the soil surface vs. application directly into water.

### CONCLUSIONS

A total of 1.72, 5.40 and 11.03% of carbofuran applied to three commercial rice fields was discharged in runoff water within 80 d after flooding the fields.

Several factors indicated that carbofuran residues discharged from rice fields in runoff water were the sole major source of carbofuran mass found in agricultural drains and the Sacramento River in 1987 and 1988. A

comparison of the potential mass of carbofuran discharged from rice and sugar beet fields in Colusa, Glenn and Yolo Counties from April through July, 1988 indicated that rice runoff water contributed an eleven-fold greater mass to agricultural drain water than did sugar beet runoff. Additionally, peak concentrations of carbofuran were detected in agricultural drain water from April to the first half of May when very little carbofuran was applied to sugar beet fields. Concentrations of carbofuran in several agricultural drains indicated that major sources of residues were north of Yolo County where most of the carbofuran use is in rice fields.

Maximum concentrations of carbofuran in paddy soil ranged from 0.50 to 0.80 mg kg<sup>-1</sup> and occurred within 11 to 20 d after flooding. Final concentrations, at the close of the study, ranged from 0.15 to 0.57 mg kg<sup>-1</sup>. Dissipation half-lives for carbofuran incorporated into paddy soil were 58 and 43 d after flooding for Fields 1 and 2, respectively. Dissipation of carbofuran from soil was not significant in Field 3 during the 70 d sampling period.

Maximum concentrations of carbofuran in paddy water ranged from 24.5 to 38.2 µg L<sup>-1</sup> and occurred within 1 to 28 d after flooding. Concentrations ranged from 0.7 to 1.7 µg L<sup>-1</sup> by the end of the study. Paddy water dissipation half-lives for carbofuran were 22, 26 and 18 d after flooding for Fields 1, 2 and 3, respectively.

The mass of carbofuran recovered from paddy soil on the first day fields were flooded ranged from 32 to 109% of the mass applied. Low initial carbofuran mass found in paddy soils of Fields 1 and 2 may have influenced dissipation in the 7.6 cm deep zone sampled. This was reflected in the reduced total mass of carbofuran discharged in runoff water from Fields 1 and 2 when compared with Field 3. The majority of carbofuran mass incorporated into the soil remained there with no more than 27% of the mass applied found in paddy water on any single day throughout the study. Although a direct comparison with other application methods was not made,

results indicate that the amount of carbofuran released into paddy water is reduced when carbofuran is soil-incorporated. Consequently, the mass released off-field in runoff water may also be reduced. It should be noted that incorporation may increase persistence in soil and water, thereby affecting the leaching potential of carbofuran.

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## **APPENDIX I.**

California Department of Fish and Game laboratory methods for analysis of carbofuran in agricultural drain water samples, 1988.

California Department of Fish and Game laboratory methods for analysis of carbofuran in agricultural drain water samples, 1988.

The methylene chloride extracts of carbofuran from the water samples were dried with granular sodium sulfate to near dryness. Petroleum ether was added and the methylene chloride was evaporated. The petroleum ether concentrate was adjusted to a suitable volume for analysis using a Varian Aerograph Model 3700 gas chromatograph with the following conditions:

Column: 6% UL-1, length: 183 cm  
I.D. : 2mm  
Detector Temperature: 250°C  
Injector Temperature: 210°C  
Column Temperature : 150°C  
Carrier Gas: N<sub>2</sub>  
Carrier Flow: 40 ml/min  
Detector : TSD  
Detection Limit: 1 µg/liter carbofuran

## **APPENDIX II.**

Split sample results for carbofuran in rice paddy soil and water.

Split sample results for carbofuran in rice paddy soil and water from California Analytical Laboratories (CAL) (primary laboratory) and the California Department of Food and Agriculture (CDFA) laboratory (quality control laboratory).

Soil ( $\text{mg kg}^{-1}$ )			Water ( $\mu\text{g L}^{-1}$ )		
CAL	CDFA	Difference CAL-CDFA	CAL	CDFA	Difference CAL-CDFA
0.72	0.63	0.09	12.6	14.3	-1.7
0.41	0.47	-0.06	8.3	6.4	1.9
0.24	0.24	0.00	10.2	8.8	1.4
0.27	0.23	0.04	7.6	3.7	3.9
0.34	0.34	0.00	5.8	2.2	3.6
0.22	0.21	0.01	4.7	2.5	2.2
			8.3	1.2	7.1
			9.0	2.8	6.2
			1.4	0.2	1.2
			2.5	1.3	1.2
			1.4	0.4	1.0

Results for Paired  $t$ -Tests<sup>a</sup> of carbofuran soil and water samples.

	Soil	Water
No. of Observations	6	11
Mean	0.014 ( $\text{mg kg}^{-1}$ )	2.6 ( $\mu\text{g L}^{-1}$ )
Standard Error	0.019 ( $\text{mg kg}^{-1}$ )	0.8 ( $\mu\text{g L}^{-1}$ )
$t$	0.720	3.4
Prob. > $ t $	0.504	0.01

<sup>a</sup> Test conducted using SAS Means procedure. SAS Procedures Guide. 1988. SAS Institute, Cary, NC.

### APPENDIX III.

Part A. Data for calculations of water volume released and carbofuran mass discharged from rice fields in Colusa and Glenn Counties, CA, 1988.

Part B. Daily volume of water released, percent of total volume released, daily mass of carbofuran discharged and percent of total mass discharged for three rice fields in Colusa and Glenn Counties, CA, 1988.

Part A. Data for calculations of water volume released and carbofuran mass discharged from rice fields in Colusa and Glenn Counties, CA, 1988. Water volume released (L) was the product of flow rate (L/h) and period of runoff (h). Carbofuran mass discharged (kg) was the product of water volume (L) and concentration (kg/L). Concentrations below the detection limit ( $0.5 \times 10^{-9}$  kg/L) were assumed to equal  $0.4 \times 10^{-9}$  kg/L.

----- FIELD=1 -----

Sample Date 1988	Days After Flood- ing	Runoff Flow Rate (L/h)	Period of Runoff (h)	Water Volume Released (L)	Carbofuran Concentra- tion (kg/L)	Carbofuran Mass Discharged (kg)
4 - 26	0	135581.32	13.00	1762557.12	.0000000037	.0065215
4 - 26	0	45873.38	7.00	321113.65	.0000000072	.0023120
5 - 09	13	128445.46	4.25	545893.20	.0000000052	.0028386
5 - 09	13	128445.46	1.50	192668.19	.0000000034	.0006551
5 - 22	26	23446.39	3.00	70339.18	.0000000211	.0014842
5 - 22	26	23446.39	7.50	175847.95	.0000000139	.0024443
5 - 23	27	16310.53	2.25	36698.70	.0000000139	.0005101
5 - 23	27	16310.53	12.25	199804.05	.0000000096	.0019181
5 - 23	27	16310.53	9.50	154950.08	.0000000167	.0025877
5 - 24	28	16310.53	2.50	40776.34	.0000000167	.0006810
5 - 24	28	16310.53	12.00	195726.41	.0000000084	.0016441
5 - 24	28	16310.53	9.50	154950.08	.0000000139	.0021538
5 - 25	29	16310.53	2.25	36698.70	.0000000139	.0005101
5 - 25	29	6116.45	10.75	65751.84	.0000000142	.0009337
5 - 28	32	97863.21	6.25	611645.04	.0000000124	.0075844
5 - 28	32	97863.21	9.75	954166.26	.0000000023	.0021946
5 - 29	33	16310.53	2.50	40776.34	.0000000023	.0000938
5 - 29	33	16310.53	12.00	195726.41	.0000000026	.0005089
5 - 29	33	16310.53	9.50	154950.08	.0000000032	.0004958
5 - 30	34	19368.76	2.75	53264.09	.0000000032	.0001704
5 - 30	34	19368.76	12.00	232425.12	.0000000016	.0003719
5 - 30	34	19368.76	9.25	179161.03	.0000000026	.0004658
5 - 31	35	13252.31	2.50	33130.77	.0000000026	.0000861
5 - 31	35	13252.31	12.00	159027.71	.0000000033	.0005248
5 - 31	35	13252.31	3.00	39756.93	.0000000043	.0001710
5 - 31	35	45873.38	6.50	298176.96	.0000000043	.0012822
6 - 01	36	16310.53	2.50	40776.34	.0000000043	.0001753
6 - 01	36	16310.53	12.25	199804.05	.0000000023	.0004595
6 - 01	36	16310.53	9.25	150872.44	.0000000026	.0003923
6 - 02	37	6116.45	10.00	61164.50	.0000000026	.0001590
6 - 04	39	8155.27	10.00	81552.67	.0000000029	.0002365
6 - 05	40	25485.21	3.25	82826.93	.0000000029	.0002402
6 - 05	40	25485.21	6.75	172025.17	.0000000024	.0004129
6 - 05	40	74416.81	5.50	409292.47	.0000000024	.0009823
6 - 05	40	74416.81	5.00	372084.07	.0000000009	.0003349
6 - 05	40	125387.23	3.50	438855.32	.0000000009	.0003950
6 - 06	41	161066.53	3.50	563732.85	.0000000009	.0005074
6 - 06	41	161066.53	18.25	2939464.12	.0000000004	.0011758
6 - 06	41	161066.53	2.25	362399.69	.0000000005	.0001812

----- FIELD=1 -----  
(continued)

Sample Date 1988	Days After Flood- ing	Runoff Flow Rate (L/h)	Period of Runoff (h)	Water Volume Released (L)	Carbofuran Concentra- tion (kg/L)	Carbofuran Mass Discharged (kg)
6 - 07	42	161066.53	21.75	3503196.97	.0000000005	.0017516
6 - 07	42	161066.53	2.25	362399.69	.0000000005	.0001812
6 - 08	43	133542.50	22.25	2971320.63	.0000000005	.0014857
6 - 08	43	133542.50	1.75	233699.38	.0000000008	.0001870
6 - 09	44	133542.50	23.25	3104863.13	.0000000008	.0024839
6 - 09	44	133542.50	0.75	100156.88	.0000000004	.0000401
6 - 10	45	150872.44	23.75	3583220.53	.0000000004	.0014333
6 - 10	45	150872.44	0.25	37718.11	.0000000004	.0000151
6 - 11	46	149853.03	22.50	3371693.28	.0000000004	.0013487
6 - 11	46	149853.03	1.50	224779.55	.0000000004	.0000899
6 - 12	47	124367.82	22.75	2829368.01	.0000000004	.0011317
6 - 12	47	124367.82	1.25	155459.78	.0000000009	.0001399
6 - 13	48	87669.12	22.25	1950637.97	.0000000009	.0017556
6 - 13	48	87669.12	1.75	153420.96	.0000000004	.0000614
6 - 14	49	70339.18	21.75	1529877.16	.0000000004	.0006120
6 - 14	49	70339.18	2.25	158263.15	.0000000008	.0001266
6 - 15	50	70339.18	8.00	562713.44	.0000000008	.0004502
6 - 15	50	22426.98	13.50	302764.29	.0000000008	.0002422
6 - 15	50	22426.98	2.50	56067.46	.0000000017	.0000953
6 - 16	51	16310.53	21.75	354754.12	.0000000017	.0006031
6 - 16	51	16310.53	2.25	36698.70	.0000000022	.0000807
6 - 17	52	8155.27	21.50	175338.24	.0000000022	.0003857
6 - 17	52	8155.27	2.50	20388.17	.0000000054	.0001101
6 - 18	53	15291.13	21.25	324936.43	.0000000054	.0017547
6 - 18	53	15291.13	2.75	42050.60	.0000000041	.0001724
6 - 19	54	2038.82	24.00	48931.60	.0000000041	.0002006
6 - 20	55	1019.41	9.50	9684.38	.0000000041	.0000397
6 - 20	55	1019.41	14.50	14781.42	.0000000048	.0000710
6 - 21	56	6116.45	21.75	133032.80	.0000000048	.0006386
6 - 21	56	6116.45	2.25	13762.01	.0000000020	.0000275
6 - 22	57	19368.76	22.25	430954.90	.0000000020	.0008619
6 - 22	57	19368.76	1.75	33895.33	.0000000021	.0000712
6 - 23	58	49951.01	22.25	1111410.01	.0000000021	.0023340
6 - 23	58	49951.01	1.75	87414.27	.0000000011	.0000962
6 - 24	59	93785.57	22.50	2110175.39	.0000000011	.0023212
6 - 24	59	93785.57	1.50	140678.36	.0000000007	.0000985
6 - 25	60	127426.05	22.25	2835229.61	.0000000007	.0019847
6 - 25	60	127426.05	1.75	222995.59	.0000000006	.0001338
6 - 26	61	118251.37	22.00	2601530.24	.0000000006	.0015609
6 - 26	61	118251.37	2.00	236502.75	.0000000010	.0002365
6 - 27	62	101940.84	24.00	2446580.16	.0000000010	.0024466
6 - 28	63	101940.84	23.00	2344639.32	.0000000010	.0023446
6 - 28	63	101940.84	1.00	101940.84	.0000000006	.0000612
6 - 29	64	101940.84	24.00	2446580.16	.0000000006	.0014679
6 - 30	65	101940.84	24.00	2446580.16	.0000000006	.0014679
7 - 01	66	110096.11	24.00	2642306.57	.0000000006	.0015854

----- FIELD=1 -----  
(continued)

Sample Date 1988	Days After Flood- ing	Runoff Flow Rate (L/h)	Period of Runoff (h)	Water Volume Released (L)	Carbofuran Concentra- tion (kg/L)	Carbofuran Mass Discharged (kg)
7 - 02	67	117231.97	22.75	2667027.23	.0000000001	.0016002
7 - 02	67	117231.97	1.25	146539.96	.0000000001	.0000733
7 - 03	68	118251.37	24.00	2838032.99	.0000000001	.0014190
7 - 04	69	127426.05	24.00	3058225.20	.0000000001	.0015291
7 - 05	70	135581.32	24.00	3253951.61	.0000000001	.0016270
7 - 06	71	142717.18	10.00	1427171.76	.0000000001	.0007136
7 - 06	71	142717.18	14.00	1998040.46	.0000000001	.0019980
7 - 07	72	150872.44	24.00	3620938.64	.0000000001	.0036209

----- FIELD=2 -----

Sample Date 1988	Days After Flood- ing	Runoff Flow Rate (L/h)	Period of Runoff (h)	Water Volume Released (L)	Carbofuran Concentra- tion (kg/L)	Carbofuran Mass Discharged (kg)
4 - 18	0	16310.53	11.00	179415.88	.00000000052	0.000933
4 - 18	0	63203.32	1.75	110605.81	.00000000052	0.000575
4 - 18	0	63203.32	6.25	395020.76	.00000000213	0.008414
4 - 18	0	63203.32	5.00	316016.60	.00000000067	0.002117
4 - 19	1	133542.50	4.75	634326.88	.00000000067	0.004250
4 - 19	1	133542.50	7.25	968183.13	.00000000085	0.008230
4 - 19	1	175338.24	3.25	569849.30	.00000000085	0.004844
4 - 19	1	175338.24	4.50	789022.10	.00000000068	0.005365
4 - 19	1	175338.24	4.25	745187.54	.00000000060	0.004471
4 - 20	2	153930.67	5.00	769653.34	.00000000060	0.004618
4 - 20	2	153930.67	8.50	1308410.68	.00000000085	0.011121
4 - 20	2	153930.67	4.00	615722.67	.00000000077	0.004741
4 - 20	2	153930.67	6.50	1000549.34	.00000000088	0.008805
4 - 21	3	56067.46	2.25	126151.79	.00000000088	0.001110
4 - 21	3	56067.46	10.50	588708.35	.00000000059	0.003473
4 - 21	3	56067.46	5.50	308371.04	.00000000068	0.002097
4 - 21	3	56067.46	5.75	322387.91	.00000000071	0.002289
4 - 22	4	56067.46	2.75	154185.52	.00000000071	0.001095
4 - 22	4	56067.46	9.25	518624.02	.00000000065	0.003371
4 - 22	4	56067.46	5.00	280337.31	.00000000099	0.002775
4 - 22	4	56067.46	7.00	392472.23	.00000000073	0.002865
4 - 23	5	73397.40	2.50	183493.51	.00000000073	0.001340
4 - 23	5	73397.40	10.00	733974.05	.00000000066	0.004844
4 - 23	5	73397.40	5.00	366987.02	.00000000060	0.002202
4 - 23	5	73397.40	6.50	477083.13	.00000000067	0.003196

----- FIELD=2 -----  
(continued)

Sample Date 1988	Days After Flood- ing	Runoff Flow Rate (L/h)	Period of Runoff (h)	Water Volume Released (L)	Carbofuran Concentra- tion (kg/L)	Carbofuran Mass Discharged (kg)
4 - 24	6	91746.76	2.25	206430.20	.0000000067	0.001383
4 - 24	6	91746.76	9.75	894530.87	.0000000054	0.004830
4 - 24	6	91746.76	5.25	481670.47	.0000000051	0.002457
4 - 24	6	91746.76	6.75	619290.60	.0000000048	0.002973
4 - 25	7	91746.76	3.25	298176.96	.0000000048	0.001431
4 - 25	7	91746.76	8.75	802784.11	.0000000055	0.004415
4 - 25	7	91746.76	4.75	435797.09	.0000000030	0.001307
4 - 25	7	91746.76	7.25	665163.98	.0000000032	0.002129
4 - 26	8	91746.76	3.00	275240.27	.0000000032	0.000881
4 - 26	8	91746.76	4.50	412860.40	.0000000049	0.002023
4 - 26	8	14271.72	5.50	78494.45	.0000000049	0.000385
4 - 26	8	14271.72	4.75	67790.66	.0000000030	0.000203
4 - 26	8	14271.72	6.25	89198.24	.0000000044	0.000392
4 - 27	9	22426.98	3.00	67280.95	.0000000044	0.000296
4 - 27	9	22426.98	9.00	201842.86	.0000000043	0.000868
4 - 27	9	22426.98	4.25	95314.69	.0000000044	0.000419
4 - 27	9	22426.98	7.75	173809.13	.0000000057	0.000991
4 - 28	10	22426.98	8.50	190629.37	.0000000057	0.001087
5 - 11	23	94804.98	7.50	711037.36	.0000000164	0.011661
5 - 11	23	94804.98	10.00	948049.81	.0000000147	0.013936
5 - 12	24	94804.98	2.25	213311.21	.0000000147	0.003136
5 - 12	24	94804.98	5.75	545128.64	.0000000114	0.006214
5 - 12	24	152911.26	6.25	955695.38	.0000000114	0.010895
5 - 12	24	152911.26	9.75	1490884.78	.0000000328	0.048901
5 - 13	25	104999.07	2.00	209998.13	.0000000328	0.006888
5 - 13	25	104999.07	12.00	1259988.78	.0000000256	0.032256
5 - 13	25	104999.07	10.00	1049990.65	.0000000300	0.031500
5 - 14	26	87669.12	2.25	197255.53	.0000000300	0.005918
5 - 14	26	87669.12	12.25	1073946.75	.0000000328	0.035225
5 - 14	26	87669.12	9.50	832856.66	.0000000187	0.015574
5 - 15	27	18349.35	2.75	50460.72	.0000000187	0.000944
5 - 15	27	18349.35	9.25	169731.50	.0000000142	0.002410
5 - 18	30	10194.08	4.25	43324.86	.0000000121	0.000524
5 - 18	30	10194.08	2.75	28033.73	.0000000041	0.000115
5 - 18	30	26504.62	4.00	106018.47	.0000000041	0.000435
5 - 19	31	41795.74	2.75	114938.30	.0000000041	0.000471
5 - 19	31	41795.74	11.75	491100.00	.0000000048	0.002357
5 - 19	31	41795.74	9.50	397059.57	.0000000045	0.001787
5 - 20	32	55048.05	2.75	151382.15	.0000000045	0.000681
5 - 20	32	55048.05	11.75	646814.63	.0000000017	0.001100
5 - 20	32	55048.05	9.50	522956.51	.0000000027	0.001412
5 - 21	33	94804.98	2.25	213311.21	.0000000027	0.000576

----- FIELD=2 -----  
(continued)

Sample Date 1988	Days After Flood- ing	Runoff Flow Rate (L/h)	Period of Runoff (h)	Water Volume Released (L)	Carbofuran Concentra- tion (kg/L)	Carbofuran Mass Discharged (kg)
5 - 21	33	94804.98	12.25	1161361.02	.0000000024	.0027873
5 - 21	33	94804.98	9.50	900647.32	.0000000039	.0035125
5 - 22	34	106018.47	2.25	238541.57	.0000000039	.0009303
5 - 22	34	106018.47	12.00	1272221.68	.0000000027	.0034350
5 - 22	34	106018.47	9.75	1033680.12	.0000000019	.0019640
5 - 23	35	106018.47	2.25	238541.57	.0000000019	.0004532
5 - 23	35	106018.47	12.00	1272221.68	.0000000013	.0016539
5 - 23	35	106018.47	9.75	1033680.12	.0000000032	.0033078
5 - 24	36	106018.47	2.50	265046.18	.0000000032	.0008481
5 - 24	36	106018.47	12.25	1298726.30	.0000000014	.0018182
5 - 24	36	106018.47	9.25	980670.88	.0000000014	.0013729
5 - 25	37	94804.98	2.25	213311.21	.0000000014	.0002986
5 - 25	37	94804.98	17.75	1682788.42	.0000000015	.0025242
5 - 25	37	94804.98	4.00	379219.92	.0000000012	.0004551
5 - 26	38	72378.00	24.00	1737071.91	.0000000012	.0020845
5 - 27	39	45873.38	8.00	366987.02	.0000000012	.0004404
5 - 30	42	8155.27	12.00	97863.21	.0000000050	.0004893
5 - 30	42	8155.27	3.00	24465.80	.0000000013	.0000318
5 - 31	43	22426.98	20.75	465359.93	.0000000013	.0006050
5 - 31	43	22426.98	3.25	72887.70	.0000000014	.0001020
6 - 01	44	61164.50	21.00	1284454.58	.0000000014	.0017982
6 - 01	44	61164.50	3.00	183493.51	.0000000010	.0001835
6 - 02	45	94804.98	21.25	2014605.85	.0000000010	.0020146
6 - 02	45	94804.98	2.75	260713.70	.0000000012	.0003129
6 - 03	46	100921.43	21.75	2195041.14	.0000000012	.0026340
6 - 03	46	100921.43	2.25	227073.22	.0000000016	.0003633
6 - 04	47	97863.21	22.25	2177456.34	.0000000016	.0034839
6 - 04	47	97863.21	1.75	171260.61	.0000000014	.0002398
6 - 05	48	66261.55	22.50	1490884.78	.0000000014	.0020872
6 - 05	48	66261.55	1.50	99392.32	.0000000013	.0001292
6 - 06	49	66261.55	21.75	1441188.63	.0000000013	.0018735
6 - 06	49	66261.55	2.25	149088.48	.0000000008	.0001193
6 - 07	50	78494.45	21.75	1707254.22	.0000000008	.0013658
6 - 07	50	78494.45	2.25	176612.51	.0000000006	.0001060
6 - 08	51	87669.12	23.00	2016389.82	.0000000006	.0012098
6 - 08	51	87669.12	1.00	87669.12	.0000000010	.0000877
6 - 09	52	81552.67	24.00	1957264.13	.0000000010	.0019573
6 - 10	53	87669.12	23.25	2038307.10	.0000000006	.0012230
6 - 10	53	87669.12	0.75	65751.84	.0000000004	.0000263
6 - 11	54	81552.67	22.50	1834935.12	.0000000004	.0007340
6 - 11	54	81552.67	1.50	122329.01	.0000000004	.0000489
6 - 12	55	81552.67	22.00	1794158.78	.0000000004	.0007177

----- FIELD=2 -----  
(continued)

Sample Date 1988	Days After Flood- ing	Runoff Flow Rate (L/h)	Period of Runoff (h)	Water Volume Released (L)	Carbofuran Concentra- tion (kg/L)	Carbofuran Mass Discharged (kg)
6 - 12	55	81552.67	2.00	163105.34	.0000000004	.0000652
6 - 13	55	66261.55	21.75	1441188.63	.0000000004	.0005765
6 - 13	55	66261.55	2.25	149088.48	.0000000004	.0000596
6 - 14	57	48931.60	24.00	1174358.48	.0000000004	.0004697
6 - 15	58	48931.60	9.75	477083.13	.0000000004	.0001908
6 - 15	58	48931.60	14.25	697275.35	.0000000007	.0004881
6 - 16	59	54028.65	24.00	1296687.48	.0000000007	.0009077
6 - 17	60	38737.52	24.00	929700.46	.0000000007	.0006508
6 - 18	61	22426.98	10.00	224269.85	.0000000007	.0001570
6 - 18	61	22426.98	14.00	313977.79	.0000000015	.0004710
6 - 19	62	22426.98	24.00	538247.64	.0000000015	.0008074
6 - 20	63	38737.52	24.00	929700.46	.0000000015	.0013946
6 - 21	64	38737.52	22.00	852225.42	.0000000015	.0012783
6 - 21	64	38737.52	2.00	77475.04	.0000000010	.0000775
6 - 22	65	35679.29	24.00	856303.06	.0000000010	.0008563
6 - 23	66	35679.29	24.00	856303.06	.0000000010	.0008563
6 - 24	67	38737.52	24.00	929700.46	.0000000010	.0009297
6 - 25	68	43834.56	10.75	471221.53	.0000000010	.0004712
6 - 25	68	43834.56	13.25	580807.94	.0000000014	.0008131
6 - 26	69	48931.60	24.00	1174358.48	.0000000014	.0016441
6 - 27	70	51989.83	24.00	1247755.88	.0000000014	.0017469
6 - 28	71	43834.56	23.50	1030112.19	.0000000014	.0014422
6 - 28	71	43834.56	0.50	21917.28	.0000000016	.0000351
6 - 29	72	40776.34	24.00	978632.06	.0000000016	.0015658
6 - 30	73	31601.66	24.00	758439.85	.0000000016	.0012135
7 - 01	74	43834.56	24.00	1052029.47	.0000000016	.0016832
7 - 02	75	54028.65	24.00	1296687.48	.0000000016	.0020747
7 - 03	76	69319.77	23.00	1594354.74	.0000000016	.0025510
7 - 03	76	69319.77	1.00	69319.77	.0000000006	.0000416
7 - 04	77	81552.67	24.00	1957264.13	.0000000006	.0011744
7 - 05	78	87669.12	24.00	2104058.94	.0000000006	.0012624
7 - 06	79	87669.12	24.00	2104058.94	.0000000006	.0012624
7 - 07	80	87669.12	24.00	2104058.94	.0000000006	.0012624

----- FIELD=3 -----

Sample Date 1988	Days After Flood- ing	Runoff Flow Rate (L/h)	Period of Runoff (h)	Water Volume Released (L)	Carbofuran Concentra- tion (kg/L)	Carbofuran Mass Discharged (kg)
4 - 19	1	50970.42	2.00	101940.84	.0000000271	0.002763
4 - 19	1	50970.42	4.50	229366.89	.0000000209	0.004794
4 - 20	2	71358.59	3.75	267594.71	.0000000209	0.005593
4 - 20	2	71358.59	9.50	677906.59	.0000000230	0.015592
4 - 20	2	71358.59	4.50	321113.65	.0000000106	0.003404
4 - 20	2	71358.59	6.25	445991.17	.0000000089	0.003969
4 - 21	3	91746.76	2.50	229366.89	.0000000089	0.002041
4 - 21	3	91746.76	8.75	802784.11	.0000000148	0.011881
4 - 21	3	91746.76	5.20	477083.13	.0000000062	0.002958
4 - 21	3	91746.76	7.25	665163.98	.0000000080	0.005321
4 - 22	4	98882.61	2.75	271927.19	.0000000080	0.002175
4 - 22	4	98882.61	10.50	1038267.46	.0000000163	0.016924
4 - 22	4	98882.61	4.75	469692.42	.0000000152	0.007139
4 - 22	4	98882.61	6.00	593295.69	.0000000162	0.009611
4 - 23	5	117231.97	2.50	293079.91	.0000000162	0.004748
4 - 23	5	117231.97	9.50	1113703.68	.0000000146	0.016260
4 - 23	5	117231.97	5.00	586159.83	.0000000132	0.007737
4 - 23	5	117231.97	7.00	820623.76	.0000000140	0.011489
4 - 24	6	107037.88	2.00	214075.76	.0000000140	0.002997
4 - 24	6	107037.88	9.50	1016859.88	.0000000089	0.009050
4 - 24	6	107037.88	5.25	561948.88	.0000000059	0.003315
4 - 24	6	107037.88	7.25	776024.64	.0000000064	0.004967
4 - 25	7	83591.49	2.00	167182.98	.0000000064	0.001070
4 - 25	7	83591.49	9.75	815017.02	.0000000109	0.008884
4 - 25	7	83591.49	5.75	480651.06	.0000000102	0.004903
4 - 25	7	83591.49	6.50	543344.68	.0000000069	0.003749
4 - 26	8	62183.91	2.50	155459.78	.0000000069	0.001073
4 - 26	8	62183.91	9.50	590747.17	.0000000058	0.003426
4 - 26	8	62183.91	5.25	326465.54	.0000000088	0.002873
4 - 26	8	62183.91	6.75	419741.41	.0000000095	0.003988
4 - 27	9	60145.10	2.00	120290.19	.0000000095	0.001143
4 - 27	9	60145.10	8.75	526269.59	.0000000070	0.003684
4 - 27	9	60145.10	4.75	285689.20	.0000000052	0.001486
4 - 27	9	60145.10	8.50	511233.31	.0000000032	0.001636
4 - 28	10	47912.19	1.50	71868.29	.0000000032	0.000230
4 - 28	10	47912.19	10.00	479121.95	.0000000058	0.002779
4 - 28	10	47912.19	4.25	203626.83	.0000000075	0.001527
4 - 28	10	47912.19	8.25	395275.61	.0000000070	0.002767
4 - 29	11	12232.90	6.00	73397.40	.0000000070	0.000514
5 - 18	30	273201.45	7.50	2049010.88	.0000000073	0.014958
5 - 19	31	244658.02	2.00	489316.03	.0000000073	0.003572
5 - 19	31	244658.02	11.75	2874731.69	.0000000060	0.017248
5 - 19	31	244658.02	10.25	2507744.66	.0000000052	0.013040

----- FIELD=3 -----  
(continued)

Sample Date 1988	Days After Flood- ing	Runoff Flow Rate (L/h)	Period of Runoff (h)	Water Volume Released (L)	Carbofuran Concentra- tion (kg/L)	Carbofuran Mass Discharged (kg)
5 - 20	32	244658.02	2.00	489316.03	.0000000052	0.002544
5 - 20	32	244658.02	5.00	1223290.08	.0000000063	0.007707
5 - 20	32	466889.05	7.50	3501667.85	.0000000063	0.022061
5 - 20	32	466889.05	1.00	466889.05	.0000000062	0.002895
5 - 20	32	411840.99	8.50	3500648.45	.0000000062	0.021704
5 - 21	33	383297.56	2.25	862419.51	.0000000062	0.005347
5 - 21	33	383297.56	9.75	3737151.19	.0000000053	0.019807
5 - 21	33	370045.25	2.00	740090.50	.0000000053	0.003922
5 - 21	33	370045.25	10.00	3700452.49	.0000000087	0.032194
5 - 22	34	383297.56	1.75	670770.73	.0000000087	0.005836
5 - 22	34	383297.56	5.25	2012312.18	.0000000068	0.013684
5 - 22	34	28543.44	6.25	178396.47	.0000000068	0.001213
5 - 22	34	28543.44	10.75	306841.93	.0000000053	0.001626
5 - 23	35	69319.77	1.25	86649.71	.0000000053	0.000459
5 - 23	35	69319.77	10.75	745187.54	.0000000045	0.003353
5 - 23	35	99902.02	1.50	149853.03	.0000000045	0.000674
5 - 23	35	99902.02	10.50	1048971.24	.0000000055	0.005769
5 - 24	36	116212.56	1.75	203371.98	.0000000055	0.001119
5 - 24	36	116212.56	6.25	726328.48	.0000000066	0.004794
5 - 24	36	181454.70	6.50	1179455.52	.0000000066	0.007784
5 - 24	36	181454.70	2.50	453636.74	.0000000050	0.002268
5 - 24	36	175338.24	7.00	1227367.71	.0000000050	0.006137
5 - 25	37	155969.49	3.25	506900.83	.0000000050	0.002535
5 - 25	37	155969.49	4.75	740855.05	.0000000035	0.002593
5 - 25	37	155969.49	7.00	1091786.40	.0000000035	0.003821
5 - 25	37	155969.49	9.00	1403725.37	.0000000050	0.007019
5 - 26	38	155969.49	3.00	467908.46	.0000000050	0.002340
5 - 26	38	155969.49	5.50	857832.17	.0000000028	0.002402
5 - 26	38	202862.27	6.75	1369320.33	.0000000028	0.003834
5 - 26	38	202862.27	8.75	1775044.88	.0000000037	0.006568
5 - 27	39	146794.81	3.25	477083.13	.0000000037	0.001765
5 - 27	39	146794.81	11.75	1724839.01	.0000000021	0.003622
5 - 27	39	146794.81	9.00	1321153.29	.0000000029	0.003831
5 - 28	40	146794.81	3.00	440384.43	.0000000029	0.001277
5 - 28	40	146794.81	5.50	807371.45	.0000000037	0.002987
5 - 28	40	937855.73	6.50	6096062.23	.0000000037	0.022555
5 - 28	40	937855.73	2.50	2344639.32	.0000000014	0.003282
5 - 28	40	993923.19	6.50	6460500.73	.0000000014	0.009045
5 - 29	41	830817.85	2.25	1869340.15	.0000000014	0.002617
5 - 29	41	830817.85	9.75	8100474.00	.0000000010	0.008100
5 - 29	41	705430.61	8.00	5643444.90	.0000000010	0.005643
5 - 29	41	705430.61	4.00	2821722.45	.0000000021	0.005926

----- FIELD=3 -----  
(continued)

Sample Date 1988	Days After Flood- ing	Runoff Flow Rate (L/h)	Period of Runoff (h)	Water Volume Released (L)	Carbofuran Concentra- tion (kg/L)	Carbofuran Mass Discharged (kg)
5 - 30	42	575965.75	7.50	4319743.09	.0000000021	0.009071
5 - 30	42	496451.89	12.50	6205648.63	.0000000021	0.013032
5 - 30	42	496451.89	4.00	1985807.56	.0000000029	0.005759
5 - 31	43	162085.94	17.00	2755460.91	.0000000029	0.007991
6 - 03	46	28543.44	7.50	214075.76	.0000000033	0.000706
6 - 04	47	69319.77	2.25	155969.49	.0000000033	0.000515
6 - 04	47	69319.77	5.75	398588.68	.0000000021	0.000837
6 - 04	47	88688.53	14.75	1308155.83	.0000000021	0.002747
6 - 04	47	88688.53	1.25	110860.66	.0000000011	0.000122
6 - 05	48	97863.21	23.75	2324251.15	.0000000011	0.002557
6 - 05	48	97863.21	0.25	24465.80	.0000000010	0.000024
6 - 06	49	97863.21	9.00	880768.86	.0000000010	0.000881
6 - 06	49	297667.25	13.75	4092924.73	.0000000010	0.004093
6 - 06	49	297667.25	1.25	372084.07	.0000000008	0.000298
6 - 07	50	308880.75	21.75	6718156.21	.0000000008	0.005375
6 - 07	50	308880.75	2.25	694981.68	.0000000008	0.000556
6 - 08	51	286453.76	21.75	6230369.29	.0000000008	0.004984
6 - 08	51	286453.76	2.25	644520.96	.0000000016	0.001031
6 - 09	52	223250.44	22.50	5023134.89	.0000000016	0.008037
6 - 09	52	223250.44	1.50	334875.66	.0000000007	0.000234
6 - 10	53	190629.37	22.50	4289160.84	.0000000007	0.003002
6 - 10	53	190629.37	1.50	285944.06	.0000000010	0.000286
6 - 11	54	190629.37	15.00	2859440.56	.0000000010	0.002859

Part B. Daily volume of water released, percent of total volume released, daily mass of carbofuran discharged and percent of total mass discharged for three rice fields in Colusa and Glenn Counties, CA, 1988.

----- FIELD=1 -----

		Runoff Water Volume		Carbofuran Mass Discharged	
		Daily Total (L)	% Total Volume Released	Daily Total (kg)	% Total Mass Discharged
Date of Discharge 1988	Days After Flooding				
04 - 26	0	2083670.77	2.59	0.00883348	9.19
05 - 09	13	738561.39	0.92	0.00349372	3.63
05 - 22	26	246187.13	0.31	0.00392844	4.09
05 - 23	27	391452.83	0.49	0.00501590	5.22
05 - 24	28	391452.83	0.49	0.00447887	4.66
05 - 25	29	102450.54	0.13	0.00144379	1.50
05 - 28	32	1565811.30	1.95	0.00977898	10.17
05 - 29	33	391452.83	0.49	0.00109851	1.14
05 - 30	34	464850.23	0.58	0.00100814	1.05
05 - 31	35	530092.37	0.66	0.00206405	2.15
06 - 01	36	391452.83	0.49	0.00102716	1.07
06 - 02	37	61164.50	0.08	0.00015903	0.17
06 - 04	39	81552.67	0.10	0.00023650	0.25
06 - 05	40	1475083.95	1.83	0.00236521	2.46
06 - 06	41	3865596.65	4.81	0.00186435	1.94
06 - 07	42	3865596.65	4.81	0.00193280	2.01
06 - 08	43	3205020.01	3.99	0.00167262	1.74

(CONTINUED)

		Runoff Water Volume		Carbofuran Mass Discharged	
		Daily Total (L)	% Total Volume Released	Daily Total (kg)	% Total Mass Discharged
Date of Discharge 1988	Days After Flooding				
06 - 09	44	3205020.01	3.99	0.00252395	2.62
06 - 10	45	3620938.64	4.50	0.00144838	1.51
06 - 11	46	3596472.84	4.47	0.00143859	1.50
06 - 12	47	2984827.80	3.71	0.00127166	1.32
06 - 13	48	2104058.94	2.62	0.00181694	1.89
06 - 14	49	1688140.31	2.10	0.00073856	0.77
06 - 15	50	921545.19	1.15	0.00078770	0.82
06 - 16	51	391452.83	0.49	0.00068382	0.71
06 - 17	52	195726.41	0.24	0.00049584	0.52
06 - 18	53	366987.02	0.46	0.00192706	2.00
06 - 19	54	48931.60	0.06	0.00020062	0.21
06 - 20	55	24465.80	0.03	0.00011066	0.12
06 - 21	56	146794.81	0.18	0.00066608	0.69
06 - 22	57	464850.23	0.58	0.00093309	0.97
06 - 23	58	1198824.28	1.49	0.00243012	2.53
06 - 24	59	2250853.75	2.80	0.00241967	2.52
06 - 25	60	3058225.20	3.80	0.00211846	2.20

(CONTINUED)

		Runoff Water Volume		Carbofuran Mass Discharged	
		Daily Total (L)	% Total Volume Released	Daily Total (kg)	% Total Mass Discharged
Date of Discharge 1988	Days After Flooding				
06 - 26	61	2838032.99	3.53	0.00179742	1.87
06 - 27	62	2446580.16	3.04	0.00244658	2.54
06 - 28	63	2446580.16	3.04	0.00240580	2.50
06 - 29	64	2446580.16	3.04	0.00146795	1.53
06 - 30	65	2446580.16	3.04	0.00146795	1.53
07 - 01	66	2642306.57	3.29	0.00158538	1.65
07 - 02	67	2813567.18	3.50	0.00167349	1.74
07 - 03	68	2838032.99	3.53	0.00141902	1.48
07 - 04	69	3058225.20	3.80	0.00152911	1.59
07 - 05	70	3253951.61	4.05	0.00162698	1.69
07 - 06	71	3425212.22	4.26	0.00271163	2.82
07 - 07	72	3620938.64	4.50	0.00362094	3.77
Total		80396153.17	100.00	0.09616497	100.00

		Runoff Water Volume		Carbofuran Mass Discharged	
		Daily Total (L)	% Total Volume Released	Daily Total (kg)	% Total Mass Discharged
Date of Discharge 1988	Days After Flooding				
04 - 18	0	1001059.05	1.00	0.01203937	2.71
04 - 19	1	3706568.94	3.71	0.02715974	6.11
04 - 20	2	3694336.04	3.69	0.02928531	6.58
04 - 21	3	1345619.09	1.35	0.00896939	2.02
04 - 22	4	1345619.09	1.35	0.01010616	2.27
04 - 23	5	1761537.72	1.76	0.01158211	2.60
04 - 24	6	2201922.14	2.20	0.01164266	2.62
04 - 25	7	2201922.14	2.20	0.00928248	2.09
04 - 26	8	923584.01	0.92	0.00388425	0.87
04 - 27	9	538247.64	0.54	0.00257406	0.58
04 - 28	10	190629.37	0.19	0.00108659	0.24
05 - 11	23	1659087.17	1.66	0.02559734	5.75
05 - 12	24	3205020.01	3.20	0.06914609	15.54
05 - 13	25	2519977.56	2.52	0.07064337	15.88
05 - 14	26	2104058.94	2.10	0.05671754	12.75
05 - 15	27	220192.21	0.22	0.00335380	0.75
05 - 18	30	177377.06	0.18	0.00107384	0.24

(CONTINUED)

		Runoff Water Volume		Carbofuran Mass Discharged	
		Daily Total (L)	% Total Volume Released	Daily Total (kg)	% Total Mass Discharged
Date of Discharge 1988	Days After Flooding				
05 - 19	31	1003097.87	1.00	0.00461530	1.04
05 - 20	32	1321153.29	1.32	0.00319279	0.72
05 - 21	33	2275319.55	2.27	0.00687573	1.55
05 - 22	34	2544443.37	2.54	0.00632930	1.42
05 - 23	35	2544443.37	2.54	0.00541489	1.22
05 - 24	36	2544443.37	2.54	0.00403930	0.91
05 - 25	37	2275319.55	2.27	0.00327788	0.74
05 - 26	38	1737071.91	1.74	0.00208449	0.47
05 - 27	39	366987.02	0.37	0.00044038	0.10
05 - 30	42	122329.01	0.12	0.00052112	0.12
05 - 31	43	538247.64	0.54	0.00070701	0.16
06 - 01	44	1467948.10	1.47	0.00198173	0.45
06 - 02	45	2275319.55	2.27	0.00232746	0.52
06 - 03	46	2422114.36	2.42	0.00299737	0.67
06 - 04	47	2348716.95	2.35	0.00372370	0.84
06 - 05	48	1590277.10	1.59	0.00221645	0.50
06 - 06	49	1590277.10	1.59	0.00199282	0.45

(CONTINUED)

		Runoff Water Volume		Carbofuran Mass Discharged	
		Daily Total (L)	% Total Volume Released	Daily Total (kg)	% Total Mass Discharged
Date of Discharge 1988	Days After Flooding				
06 - 07	50	1883866.72	1.88	0.00147177	0.33
06 - 08	51	2104058.94	2.10	0.00129750	0.29
06 - 09	52	1957264.13	1.96	0.00195726	0.44
06 - 10	53	2104058.94	2.10	0.00124928	0.28
06 - 11	54	1957264.13	1.96	0.00078291	0.18
06 - 12	55	1957264.13	1.96	0.00078291	0.18
06 - 13	56	1590277.10	1.59	0.00063611	0.14
06 - 14	57	1174358.48	1.17	0.00046974	0.11
06 - 15	58	1174358.48	1.17	0.00067893	0.15
06 - 16	59	1296687.48	1.30	0.00090768	0.20
06 - 17	60	929700.46	0.93	0.00065079	0.15
06 - 18	61	538247.64	0.54	0.00062796	0.14
06 - 19	62	538247.64	0.54	0.00080737	0.18
06 - 20	63	929700.46	0.93	0.00139455	0.31
06 - 21	64	929700.46	0.93	0.00135581	0.30
06 - 22	65	856303.06	0.86	0.00085630	0.19
06 - 23	66	856303.06	0.86	0.00085630	0.19

(CONTINUED)

		Runoff Water Volume		Carbofuran Mass Discharged	
		Daily Total (L)	% Total Volume Released	Daily Total (kg)	% Total Mass Discharged
Date of Discharge 1988	Days After Flooding				
06 - 24	67	929700.46	0.93	0.00092970	0.21
06 - 25	68	1052029.47	1.05	0.00128435	0.29
06 - 26	69	1174358.48	1.17	0.00164410	0.37
06 - 27	70	1247755.88	1.25	0.00174686	0.39
06 - 28	71	1052029.47	1.05	0.00147722	0.33
06 - 29	72	978632.06	0.98	0.00156581	0.35
06 - 30	73	758439.85	0.76	0.00121350	0.27
07 - 01	74	1052029.47	1.05	0.00168325	0.38
07 - 02	75	1296687.48	1.30	0.00207470	0.47
07 - 03	76	1663674.51	1.66	0.00259256	0.58
07 - 04	77	1957264.13	1.96	0.00117436	0.26
07 - 05	78	2104058.94	2.10	0.00126244	0.28
07 - 06	79	2104058.94	2.10	0.00126244	0.28
07 - 07	80	2104058.94	2.10	0.00126244	0.28
Total		100016706.64	100.00	0.44483873	100.00

		Runoff Water Volume		Carbofuran Mass Discharged	
		Daily Total (L)	% Total Volume Released	Daily Total (kg)	% Total Mass Discharged
Date of Discharge 1988	Days After Flooding				
04 - 19	1	331307.73	0.22	0.00755636	1.26
04 - 20	2	1712606.11	1.13	0.02855771	4.77
04 - 21	3	2174398.12	1.43	0.02220180	3.71
04 - 22	4	2373182.76	1.56	0.03584989	5.99
04 - 23	5	2813567.18	1.85	0.04023401	6.72
04 - 24	6	2568909.17	1.69	0.02032917	3.39
04 - 25	7	2006195.73	1.32	0.01860538	3.11
04 - 26	8	1492413.90	0.98	0.01135945	1.90
04 - 27	9	1443482.29	0.95	0.00794817	1.33
04 - 28	10	1149892.68	0.76	0.00730302	1.22
04 - 29	11	73397.40	0.05	0.00051378	0.09
05 - 18	30	2049010.88	1.35	0.01495778	2.50
05 - 19	31	5871792.38	3.87	0.03386067	5.65
05 - 20	32	9181811.46	6.05	0.05691041	9.50
05 - 21	33	9040113.69	5.95	0.06127032	10.23
05 - 22	34	3168321.31	2.09	0.02235879	3.73
05 - 23	35	2030661.53	1.34	0.01025627	1.71

(CONTINUED)

		Runoff Water Volume		Carbofuran Mass Discharged	
		Daily Total (L)	% Total Volume Released	Daily Total (kg)	% Total Mass Discharged
Date of Discharge 1988	Days After Flooding				
05 - 24	36	3790160.43	2.50	0.02210174	3.69
05 - 25	37	3743267.64	2.47	0.01596738	2.67
05 - 26	38	4470105.83	2.94	0.01514324	2.53
05 - 27	39	3523075.43	2.32	0.00921871	1.54
05 - 28	40	16148958.17	10.64	0.03914702	6.54
05 - 29	41	18434981.51	12.14	0.02228661	3.72
05 - 30	42	12511199.29	8.24	0.02786216	4.65
05 - 31	43	2755460.91	1.81	0.00799084	1.33
06 - 03	46	214075.76	0.14	0.00070645	0.12
06 - 04	47	1973574.66	1.30	0.00422081	0.70
06 - 05	48	2348716.95	1.55	0.00258114	0.43
06 - 06	49	5345777.65	3.52	0.00527136	0.88
06 - 07	50	7413137.88	4.88	0.00593051	0.99
06 - 08	51	6874890.25	4.53	0.00601553	1.00
06 - 09	52	5358010.55	3.53	0.00827143	1.38
06 - 10	53	4575104.90	3.01	0.00328836	0.55
06 - 11	54	2859440.56	1.88	0.00285944	0.48
Total		151821002.72	100.00	0.59893569	100.00

#### APPENDIX IV.

Concentrations of carbofuran in runoff water from three sugar beet fields, Colusa County, CA, 1988.

Concentrations of carbofuran in runoff water from three sugar beet fields, Colusa County, CA, 1988.

Field	Date	Time	Sample 1	Sample 2	Average	Standard Deviation
<hr/>						
			<hr/>		<hr/>	
			ug L <sup>-1</sup>			
<hr/>						
4	5/25/88	0630	28.1	44.7	24.8	11.6
		1045	24.0	30.1		
		1230	41.9	21.6		
	5/26/88	0630	17.6	14.7		
		1035	13.0	11.8		
5	5/27/88	0730	0.8	0.8	1.2	1.1
		1245	3.6	3.0		
		1820	1.8	1.9		
	5/28/88	0715	ND <sup>1</sup>	ND		
		1240	ND	ND		
		1840	ND	ND		
6	6/4/88	1900	117.0	118.0	134.2	48.9
	6/5/88	0800	63.0	80.2		
		1250	177.0	200.0		
		1845	188.0	184.0		
	6/6/88	0720	112.0	103.0		

<sup>1</sup> Carbofuran not detected (detection limit 0.5 ug L<sup>-1</sup>); averages were calculated using a value of 0.4 ug L<sup>-1</sup> for NDs.

## APPENDIX V.

Part A. Calculations of carbofuran potential discharge values for rice fields in Colusa, Glenn and Yolo Counties, CA, 1988.

Part B. Calculations of carbofuran potential discharge values for sugar beet fields in Colusa, Glenn and Yolo Counties, CA, 1988.

Part A. Calculations of carbofuran potential discharge values for rice fields in Colusa, Glenn and Yolo Counties, CA, 1988.

Field	Carbofuran Discharged from Field <sup>a</sup>	Carbofuran Applied to Field	Total Carbofuran Applied to Rice in 3 Counties <sup>b</sup>
	----- kg a.i. -----		
1	0.0962	5.59	7618.62
2	0.4448	8.24	7618.62
3	0.5989	5.43	7618.62

Calculations<sup>c</sup>

(Fraction of applied carbofuran discharged in runoff water from field × total carbofuran (kg) in 3 counties = potential discharge (kg))

$$\text{Field 1: } (0.0962 \text{ kg} \div 5.59 \text{ kg}) \times (7618.62 \text{ kg}) = 131.11 \text{ kg}$$

$$\text{Field 2: } (0.4448 \text{ kg} \div 8.24 \text{ kg}) \times (7618.62 \text{ kg}) = 411.25 \text{ kg}$$

$$\text{Field 3: } (0.5989 \text{ kg} \div 5.43 \text{ kg}) \times (7618.62 \text{ kg}) = 840.29 \text{ kg}$$

$$\bar{X} \quad 460.88 \text{ kg}$$

$$SD \pm 362.48 \text{ kg}$$

<sup>a</sup> Refer to Appendix I.

<sup>b</sup> Data from Agricultural Commissioners in Colusa, Glenn, and Yolo Counties, CA.

<sup>c</sup> Refer to Materials and Methods Section for description of calculations.

Part B. Calculations of carbofuran potential discharge values for sugar beet fields in Colusa, Glenn and Yolo Counties, CA, 1988.

Field	Average Carbofuran Concentration in Runoff Water <sup>a</sup>	Volume of Runoff Water Discharged from Field <sup>b</sup>	Carbofuran Discharged from Field <sup>c</sup>	Carbofuran Applied to Field <sup>d</sup>	Total Carbofuran Applied to Sugar Beet Fields in 3 Counties <sup>e</sup>
	ug L <sup>-1</sup>	L	----- kg a.i. -----		
4	24.8	14,000,000	0.35	20.64	967.26
5	1.2	40,000,000	0.05	68.04	967.26
6	134.2	97,000,000	13.02	119.75	967.26

Calculations<sup>f</sup>

(Fraction of applied carbofuran discharged in runoff water from field × total carbofuran (kg) in 3 counties = potential discharge (kg))

Field 4: (0.35 kg ÷ 20.64 kg) × (967.26 kg) = 16.40 kg

Field 5: (0.05 kg ÷ 68.04 kg) × (967.26 kg) = 0.71 kg

Field 6: (13.02 kg ÷ 119.75 kg) × (967.26 kg) = 105.17 kg

$\bar{X}$  40.76 kg

SD ±56.32 kg

<sup>a</sup> Refer to Appendix IV.

<sup>b</sup> An average volume of water was calculated from measurements of runoff from sugar beet fields (Spencer et al., 1985): Average runoff volume for a single irrigation = 250,000 L ha<sup>-1</sup>; Assume four irrigations occurred between April and June, 1988 (4 × 250,000 L ha<sup>-1</sup> = 1,000,000 L ha<sup>-1</sup>). Fields 4, 5 and 6 were 14, 40 and 97 ha, respectively.

<sup>c</sup> Carbofuran discharged from sugar beet fields was calculated as the product of average concentration in runoff (ug L<sup>-1</sup>) and volume of water discharged (L), then units were converted from ug to kg.

<sup>d</sup> Carbofuran applied to sugar beet fields was estimated from application rates and hectareage information obtained from growers.

<sup>e</sup> Data from Agricultural Commissioners in Colusa, Glenn, and Yolo Counties, CA.

<sup>f</sup> Refer to Materials and Methods Section for description of calculations.

## **Appendix VI.**

Carbofuran concentration and mass in paddy soil and water from three rice fields in Colusa and Glenn Counties, CA, 1988.

Carbofuran concentration and mass in rice paddy soil and water.

Field	Days after Flood- ing	Repli- cate	Soil conc- mg/kg	Soil mass kg/ha <sup>a</sup>	Water conc- ug/L	Water mass kg/ha <sup>b</sup>
1	0	1	0.15	0.16002	12.1	0.014157
1	0	2	0.78	0.83210	12.1	0.014157
1	0	3	0.44	0.46939	8.6	0.010062
1	1	1	--c	--	24.1	0.026992
1	1	2	--	--	16.7	0.018704
1	1	3	--	--	22.3	0.024976
1	2	1	0.17	0.18136	17.8	0.013350
1	2	2	0.24	0.25603	16.6	0.012450
1	2	3	0.30	0.32004	15.2	0.011400
1	3	1	--	--	16.7	0.014863
1	3	2	--	--	17.0	0.015130
1	3	3	--	--	15.6	0.013884
1	6	1	0.25	0.26670	12.4	0.014632
1	6	2	0.75	0.80010	10.0	0.011800
1	6	3	0.33	0.35204	10.4	0.012272
1	8	1	--	--	10.2	0.012546
1	8	2	--	--	10.0	0.012300
1	8	3	--	--	9.9	0.012177
1	12	1	0.43	0.45872	6.1	0.011224
1	12	2	0.38	0.40538	6.1	0.011224
1	12	3	0.70	0.74676	5.4	0.009936
1	16	1	--	--	7.3	0.011023
1	16	2	--	--	8.9	0.013439
1	16	3	--	--	6.4	0.009664
1	20	1	0.31	0.33071	37.6	0.036848
1	20	2	0.51	0.54407	39.3	0.038514
1	20	3	0.37	0.39472	37.7	0.036946
1	24	1	--	--	10.2	0.006936
1	24	2	--	--	16.2	0.011016
1	24	3	--	--	15.9	0.010812
1	28	1	0.25	0.26670	15.8	0.006952
1	28	2	0.55	0.58674	32.8	0.014432
1	28	3	0.05	0.05334	24.5	0.010780
1	36	1	0.29	0.30937	7.5	0.003150
1	36	2	0.23	0.24536	6.2	0.002604
1	36	3	0.20	0.21336	6.8	0.002856
1	44	1	0.17	0.18136	1.2	0.001476
1	44	2	0.29	0.30937	1.7	0.002091
1	44	3	0.63	0.67208	1.4	0.001722
1	52	1	0.15	0.16002	3.8	0.002470
1	52	2	0.13	0.13868	6.8	0.004420
1	52	3	0.22	0.23470	8.3	0.005395

(Continued)

Field	Days after Flood- ing	Repli- cate	Soil conc- mg/kg	Soil mass kg/ha	Water conc- ug/L	Water mass kg/ha
1	60	1	0.14	0.14935	1.6	0.002256
1	60	2	0.23	0.24536	3.0	0.004230
1	60	3	0.20	0.21336	2.4	0.003384
1	70	1	0.24	0.25603	0.6	0.001044
1	70	2	0.21	0.22403	1.2	0.002088
1	70	3	0.18	0.19202	1.1	0.001914
1	80	1	0.14	0.14935	1.5	0.002160
1	80	2	0.14	0.14935	1.4	0.002016
1	80	3	0.17	0.18136	0.8	0.001152
2	0	1	0.22	0.21458	10.1	0.013231
2	0	2	0.75	0.73152	10.5	0.013755
2	0	3	0.79	0.77053	8.9	0.011659
2	1	1	--	--	10.2	0.016524
2	1	2	--	--	7.4	0.011988
2	1	3	--	--	8.1	0.013122
2	2	1	0.35	0.34138	7.7	0.014861
2	2	2	0.43	0.41940	7.6	0.014668
2	2	3	0.49	0.47793	7.0	0.013510
2	4	1	--	--	6.8	0.011764
2	4	2	--	--	6.5	0.011245
2	4	3	--	--	7.6	0.013148
2	6	1	0.65	0.63398	3.8	0.006232
2	6	2	0.59	0.57546	4.4	0.007216
2	6	3	0.65	0.63398	4.5	0.007380
2	8	1	--	--	5.4	0.009180
2	8	2	--	--	4.9	0.008330
2	8	3	--	--	4.4	0.007480
2	11	1	0.59	0.57546	6.8	0.009792
2	11	2	0.45	0.43891	6.6	0.009504
2	11	3	1.10	1.07290	8.0	0.011520
2	16	1	--	--	20.8	0.019344
2	16	2	--	--	14.6	0.013578
2	16	3	--	--	11.1	0.010323
2	20	1	0.86	0.83881	7.3	0.009563
2	20	2	0.49	0.47793	5.5	0.007205
2	20	3	1.06	1.03388	5.1	0.006681
2	24	1	--	--	8.8	0.012408
2	24	2	--	--	14.7	0.020727
2	24	3	--	--	15.2	0.021432
2	28	1	0.36	0.35113	27.8	0.017792
2	28	2	0.70	0.68275	21.3	0.013632
2	28	3	0.48	0.46817	25.2	0.016128
2	36	1	0.05	0.04877	3.0	0.003870
2	36	2	0.68	0.66324	3.8	0.004902
2	36	3	0.43	0.41940	1.9	0.002451

(Continued)

Field	Days after Flood- ing	Repli- cate	Soil conc- mg/kg	Soil mass kg/ha	Water conc- ug/L	Water mass kg/ha
2	44	1	0.47	0.45842	--	--
2	44	2	0.24	0.23409	1.3	0.002275
2	44	3	0.14	0.13655	0.8	0.001400
2	52	1	0.18	0.17556	0.9	0.001575
2	52	2	0.17	0.16581	1.3	0.002275
2	52	3	0.29	0.28285	0.8	0.001400
2	60	1	0.09	0.08778	2.6	0.003952
2	60	2	0.20	0.19507	2.8	0.004256
2	60	3	0.23	0.22433	2.3	0.003496
2	70	1	0.13	0.12680	1.0	0.001860
2	70	2	0.34	0.33162	1.1	0.002046
2	70	3	0.51	0.49743	1.2	0.002232
2	80	1	0.19	0.18532	0.4	0.000832
2	80	2	0.15	0.14630	1.0	0.002080
2	80	3	0.22	0.21458	0.7	0.001456
3	0	1	0.44	0.44257	27.6	0.046092
3	0	2	0.50	0.50292	22.0	0.036740
3	0	3	1.18	1.18689	18.3	0.030561
3	1	1	--	--	23.9	0.043498
3	1	2	--	--	25.7	0.046774
3	1	3	--	--	24.0	0.043680
3	2	1	0.50	0.50292	12.2	0.023912
3	2	2	0.37	0.37216	16.7	0.032732
3	2	3	0.63	0.63368	15.7	0.030772
3	4	1	--	--	20.7	0.041400
3	4	2	--	--	13.5	0.027000
3	4	3	--	--	10.6	0.021200
3	6	1	0.27	0.27158	6.6	0.013530
3	6	2	0.49	0.49286	6.6	0.013530
3	6	3	0.15	0.15088	5.4	0.011070
3	8	1	--	--	6.8	0.013124
3	8	2	--	--	6.2	0.011966
3	8	3	--	--	8.7	0.016791
3	11	1	1.02	1.02596	8.6	0.018232
3	11	2	0.71	0.71415	8.9	0.018868
3	11	3	0.63	0.63368	6.6	0.013992
3	16	1	--	--	11.3	0.027459
3	16	2	--	--	11.5	0.027945
3	16	3	--	--	11.5	0.027945
3	20	1	0.65	0.65380	5.3	0.012720
3	20	2	0.55	0.55321	5.5	0.013200
3	20	3	0.57	0.57333	5.6	0.013440
3	24	1	--	--	14.6	0.031098
3	24	2	--	--	9.7	0.020661
3	24	3	--	--	12.5	0.026625
3	28	1	0.41	0.41239	9.3	0.018135
3	28	2	0.36	0.36210	11.6	0.022620
3	28	3	0.48	0.48280	11.4	0.022230

(Continued)

Field	Days after Flood- ing	Repli- cate	Soil conc- mg/kg	Soil mass kg/ha	Water conc- ug/L	Water mass kg/ha
3	36	1	0.43	0.43251	8.0	0.012640
3	36	2	0.25	0.25146	6.0	0.009480
3	36	3	0.62	0.62362	5.2	0.008216
3	44	1	0.90	0.90526	--	--
3	44	2	0.27	0.27158	4.2	0.005250
3	44	3	0.37	0.37216	4.7	0.005875
3	52	1	0.65	0.65380	1.4	0.001820
3	52	2	0.35	0.35204	1.6	0.002080
3	52	3	0.31	0.31181	1.8	0.002340
3	60	1	0.42	0.42245	5.6	0.007000
3	60	2	0.38	0.38222	4.2	0.005250
3	60	3	0.36	0.36210	4.7	0.005875
3	70	1	0.58	0.58339	2.1	0.001785
3	70	2	0.43	0.43251	1.1	0.000935
3	70	3	0.69	0.69403	1.8	0.001530

- a. Calculations for carbofuran mass in paddy soil were based upon border areas of 1.3, 0.8 and 1.4 ha for Fields 1, 2 and 3, respectively.
- b. Calculations for carbofuran mass in paddy water were based upon entire paddy areas of 6.5, 2.8 and 5.3 ha for Fields 1, 2 and 3, respectively.
- c. Sample not taken.